The Impact of Sustainable Forest Management on Plant and Bird Diversity in East Kalimantan, Indonesia

Arbainsyah

Dedicated to Bapak, Ibu (Alm.), Ibu Mertua, Istri, Anak-anakku, Kakak-kakak, Adik dan Keponakans

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General Introduction

Introduction

Since tropical rain forests harbor most of the world's biodiversity, tropical deforestation has become the major cause of global species extinctions (Pimm & Raven, 2000). Activities of logging are often the starting point for a cascade of interactions leading to forest destruction and habitat loss (Laurance, 1998; Meijaard *et al.*, 2005). Logging directly affects the forest by creating a more open canopy and by producing logging debris (dead wood and other dead plant material on the forest floor) which may lead to the displacement of forest floor habitats by new habitats. A more open canopy leads to increased evaporation and desiccation during dry periods, and to additional structural changes by stimulating the development of a dense undergrowth of lianas, herbs and young trees (Slik *et al.*, 2002). Apart from these direct effects, logging may also lead to an increase of local human populations and subsequent increased exploitation of the forest (Kartawinata & Vayda, 1984) and other destructive human activities such as illegal logging, poaching, and agricultural expansion (Laurance, 1998; Curran *et al.*, 2004).

Among the impacts of logging on primary forest are the mortality of canopy trees (Laurance *et al.*, 2000), recruitment failure resulting from over-predation of seeds (Curran *et al.*, 1999), reduced seedling establishment and plant growth (Slik, 2001; Bruna *et al.*, 2002; Bruna, 2003), local extinction of plants (Benitez-Malvido & Martinez-Ramos, 2003), decline in butterfly abundance and/or diversity (Cleary, 2002), decline in bird abundance and/or diversity (Boulinier *et al.*, 2001; Beier *et al.*, 2002; Slik & Van Balen, 2006), and decreased pollination (Ashworth *et al.*, 2004). Apart from ecological processes, harmful human activities, such as illegal logging and hunting, could also cause the remaining forest fragments to become less biodiverse (Laurance, 1998; Hartshorn & Bynum, 2001; Curran *et al.*, 2004).

Selectively logged forest areas may act as buffer zones and serve as a habitat for forest plants and animals displaced from destroyed primary forest areas (Brearley *et al.*, 2004; Meijaard *et al.*, 2005). Selectively logged forest areas may also act as reservoirs for recolonization and as corridors between remaining primary forest fragments. As succession proceeds, selectively logged forest areas are expected to regenerate to a stage in which they are similar in structure and composition to primary forest, as long as they are left untouched for a sufficiently long period. The time required for a disturbed forest to regenerate through succession to forest resembling primary rainforest has been estimated at 50 years (Kochummen, 1966), 50–80 years (Brown & Lugo, 1990), 73 years (Hughes *et al.*, 1999), 150–200 years (Richards, 1952; Knight, 1975), 150–500 years (Riswan *et al.*, 1985), 250–500 years (Kartawinata, 1994) and 'centuries' (Whitmore, 1991). The actual time needed to revert secondary forest to primary forest will depend on several factors, including initial environmental conditions, intensity and scale of the disturbance, length of time of abandonment, surface of forest remaining in the surrounding landscape and the distance from the seed sources of primary forest species (Brearley *et al.*, 2004; Meijaard *et al.*, 2005).

The Forest Stewardship Council (FSC)

Forest certification schemes have been introduced during the past decades in order to reduce the negative impact of logging. Sustainable Forest Management (SFM) has become an important alternative for conventional logging and is supported by international development organizations, donor agencies, and governments (Poore e*t al.*, 1989; CIFOR, 1993; FAO, 1993; ITTO, 1994; Lanly, 1995). So far, Van Kuijk *et al.* (2009) suggested that there is no quantitative evidence of an impact of FSC-certified logging on biodiversity in tropical forests.

The certification of forest management and labeling of forest products is recognized as a useful tool for promoting sustainable forest management (ITTO, 2004). Forests that have recently been certified under the four largest certification schemes cover 230 million hectares (NN, 2005). The impressive progress in the implementation of certification schemes worldwide has so far mostly been achieved in developed temperate countries of either North America or Europe, which currently account for more than 95% of the certified forest areas (Amha, 2005). The Forest Stewardship Council (FSC) reported that the demand for certified tropical hardwoods exceeds the supply by at least 12.6% logs round wood (FSC, 2014).

The major driving forces of SFM are the emerging interest of the public sector, efforts to minimize commercial risks associated with illegal timber trade, and procurement requirements established by trade associations (Oliver, 2005). Certification for SFM induces increased management costs of conventional and consequently a relatively small sample size (Van der Hoeven *et al.*, 2000; Van Kuijk *et al.*, 2009). The cost for logs is defined as the difference between the price of the certified log and the price of the same log prior to the adoption of certification (Varangis *et al.*, 1995).

Some authors claim that consumers in Europe and in the USA are willing to pay between 2% and 30% more for sustainably produced, certified tropical timber (Baharuddin & Simula, 1994; Baharuddin, 1995; Varangis *et al.*, 1995; Simula & Baharuddin, 1996; Oliver, 2005; NN, 2005). Varangis *et al.* (1995) estimated that in view of the market share of certified tropical timber on the US and European markets, the incremental revenue from the markets assumed to be willing to pay more for certified timber would amount to 62 million USD. Other authors doubt or flatly deny that the majority of consumers are willing to pay a premium for certified logs (Freris & Laschefski, 2001).

Objectively verifiable, quantitative evidence of these claims are rare as it is difficult to retrieve reliable sources of log prices, particularly in the tropics. Baharuddin and Simula (1994) conclude that "there is not yet convincing evidence of an existing price premium for sustainably produced, certified timber and timber products in the market", and after ten years, this statement still holds. Furthermore, most studies dealing with the subject are based on willingness-to-pay inquiries investigating whether or not consumers in Europe or the USA would be ready to pay a price premium. The crucial question whether or not such a premium will benefit in terms of biodiverisity to the producers of certified timber, who also bear the higher costs of sustainable forest management, is usually omitted.

Indicators for sustainable forest management

Sound management demands clear and achievable goals in which practical biodiversity conservation priorities could be achieved by reduced impact logging (Sheil, 2001). Most national conservation plans provide priorities for biodiversity conservation, such as maintaining natural vegetation cover, preventing conversion of protected areas to other land uses and protecting high-profile taxa. These are priority goals that need to be supported both locally and nationally (Sheil, 2002). However, in order to translate such strategies into real action, there is a need to develop suitable biological indicators of sustainable forest man-

agement at the forest management unit level (Ghazoul & Hellier 2000; De Iongh & Van Weerd, 2006; De Iongh & Persoon, 2010), which could be used as a monitoring tool to generate spatial and temporal data. A decision support approach using the concept of conventional based utility functions is proposed for formulating forest land use strategies to improve sustainability (De Iongh & Persoon, 2010).

In disturbed forests, species richness may even increase due to an increased number of common edge species (Johns, 1996). Species richness alone may therefore not be a good indicator of the impact of logging on forest biodiversity (Ghazoul & Hellier, 2000). Table 1.1 summarizes the conventional biological indicators/verifiers used in a number of certification systems for sustainable forest management.

Table 1.1
Target criteria used by several organizations and NGO's.

	CIFOR	ACT	ATO	ITTO	TFS	FSC	PEFC	FAO/UNEF	Smartwood	World Bank	Malaysia	Neth. Min. Req.
Species richness*	×			×	×	×	×	×		×	×	×
Species abundance	×					×					×	
Genetic diversity	×				×	×		×		×	×	
Keystone species				×	×						×	
Rare and endangered species	×	×	×	×	×	×	×	×	×		×	
Guild diversity/ abundance	×	×		×								
Population dynamic	×							×				
Hunting										×		
Invasive species	×									×		

* Often described as the number of forest depended species or species list.
Acronyms: CIFOR: Center for International Forestry Research, ACT: Amazon Cooperation Treaty, ATO: African Timber Organisation, ITTO: International Tropical Timber Organisation, TFS: Tropical Forestry Services, FAO: Food and Agriculture Organisation, FSC: Forest Stewardship Council, UNEP: United Nations Environment Program, Malaysia: Malaysian criteria and indicators for forest management, PEFC: Promoting Sustainable Forest Management, Neth. Min Req.: Netherlands criteria and indicators for forest management 'BRL'. Source: De Iongh *et al.*, 2006

This table shows that most certification systems use "species richness" as an indicator/verifier, while some use "genetic diversity", "keystone species" or "rare and endangered" species as additional indicator/verifier. It would seem that long-term recovery data will always be scarce, and this gap will only be filled by further field work (Gazhoul & Hellier, 2003).

An indicator is defined as any variable or component of the forest ecosystem or relevant management system that is used to infer attributes of the sustainability of utilization of the resource (Ghazoul & Hellier, 2000). Preventing extinctions and maintaining or enhancing the level of genetic variation among individuals, populations, and species, requires conserving or managing the dynamic forces of evolution largely at the species level (Namkoong *et al.*, 1996). At the end of the first phase of a CIFOR project, Prabhu *et al.* (1996) reported a lack of suitable indicators for assessing impacts of logging on biodiversity, at all levels of the hierarchy, and stressed the urgent need to address this weakness. They also suggest that a tool-box approach for developing and using criteria and indicators for sustainable forest management would have the highest utility for potential user groups (Gazhoul & Hellier, 2003; De Iongh *et al.*, 2006).

Ghazoul and Hellier (2000) suggest a biological protocol based on five indicators: 1. forest structure; 2. bird community structure; 3. butterfly species richness; 4. mammal species richness; 5. forest disturbance (dead wood and decomposition). Species richness alone may not be a good indicator for the recovery of forest biodiversity and for the impact of logging (Landers *et al.*, 2004; Azevedo-Ramos *et al.*, 2002; Sheil *et al.*, 2004). Some species of vascular plants (*Mallotus* spp. and *Macaranga* spp.) have been used as indicators for forest disturbance (Kessler, 1999; Slik, 2001). While the use of butterflies has been extensively covered by Cleary (2002), mammal species richness is generally more difficult to monitor due to their more extensive ranging patterns (Meijaard *et al.*, 2005). I will therefore use the present research to further investigate the use of three types of indicators: 1) forest structure (plant composition); 2) bird communities and 3) forest disturbance.

Plant composition

Plant and tree diversity in primary lowland tropical forest is impacted by logging, especially in Southeast Asia (Slik *et al.*, 2002). The surface area of primary forests in Indonesia is already surpassed by the surface area of secondary forest as a result of legal/illegal logging operations and agricultural development (Manokaran, 1992; Murali & Hedge, 1997; Sayer *et al.*, 2000; Brooks *et al.*, 2001).

Among the direct effects of logging disturbance, increased tree mortality in the forest overstorey (diameter at breast height (dbh) ≥ 10 cm) has been mentioned (Slik *et al.*, 2002). This is especially relevant in relation to the formation and persistence of forested corridors between remaining patches of undisturbed forest (Rijksen & Meijaard, 1999; Meijaard *et al.*, 2005). However, the ecological quality of secondary forests can vary considerably, depending on the kind and severity of disturbance, the time elapsed since logging took place, and the vicinity of primary forest (Brown & Lugo, 1990; Whitmore, 1991; Corlett, 1994; Chazdon, 2003). In tropical rainforests, the long-term effects of large-scale disturbances such as logging have rarely been studied (e.g. Finegan, 1996).

Mortality of trees by logging reduces the number of tree species per surface area while it increases the light levels in the forest understorey, leading to the development of dense shrubs in the undergrowth (Kartawinata *et al.,* 1981; Woods, 1989; Cannon *et al.,* 1998; Uuttera *et al.,* 2000; Slik *et al.*, 2002). Forest tree mortality is usually more pronounced in commercially logged forest, with tree mortality in conventionally logged forest suggested to be at least 2–3 times lower, and to occur mostly near and on skid trails (Woods, 1989; Webb, 1998; Pinard *et al.,* 2000; Uuttera *et al.,* 2000; Slik *et al.*, 2002). The increased light levels in the forest understorey after selective logging, usually stimulates the establishment of herbaceous and woody pioneer species (Woods, 1989; Nykvist, 1996; Pinard *et al.,* 1996; Cochrane & Schultze, 1999; Fredericksen & Mostacedo, 2000). Such pioneers could therefore be useful for detecting and quantifying tropical forest disturbance (Slik *et al.,* 2002, 2003). Slik *et al.* (2001) describe a clear pattern of increasing pioneer dominance of the genera *Mallotus* and *Macaranga* with an increasing level of disturbance (Table 1.2), thus confirming their potential importance as indicators of disturbance. Since the understorey plays an important role in the regeneration of the forest overstorey, it is likely that at least part of these pioneer species will eventually grow into forest overstorey vegetation, thus affecting the tree species composition and structure of subsequent forest stages (Riswan *et al.,* 1985; Finegan, 1996; Cochrane & Schultze, 1998; Newbery *et al.*, 2000). The abundance of pioneer species is expected to reflect the scale and severity of the disturbance that took place in a forest (Primack & Lee, 1991; Davies *et al.,* 1998; Slik *et al.*, 2002), and as such could be useful to monitor forest development after logging.

Table 1.2
The relation between pioneer and non-pioneer abundance (n per 0.3 ha plot) and disturbance type (time since disturbance between brackets). Sources: Slik *et al.* (2002).

Disturbance type	Pioneers (n ± S.D.)	Non-pioneers (n ± S.D.)	Pioneers (%)	Pioneer range (min.–max.)	Non-pioneer range (min.–max.)
Undisturbed	23.5 ± 36.4a	250.8 ± 143.4a	8.6	1–151	6–465
Logged (21) and thinning (12)	11.6 ± 9.6a	51.8 ± 37.5bc	18.3	4–27	26–113
Logged (20–30)	35.3 ± 21.6b	82.3 ± 69.9bc	30.0	19–78	2–180
Logged (10–20)	58.4 ± 44.4bc	80.3 ± 110.9bc	42.1	20–142	10–324
Logged (0–10)	138.4 ± 130.0cd	110.0 ± 78.8ab	55.7	42–376	5–196
Once burned (15)	168.2 ± 82.1de	45.6 ± 20.0bcd	78.7	82–269	15–68
Once burned (3)	507.0 ± 273.8ef	57.0 ± 39.7abcd	89.9	241–788	15–94
Once burned (1)	476.0 ± 229.3ef	16.2 ± 12.6cde	96.7	249–798	1–34
Thrice burned (3)	1124.6 ± 662.0f	35.0 ± 29.2bcd	97.0	611–2269	6–74
Twice burned (3)	1671.7 ± 1275.3f	8.3 ± 4.9de	99.5	612–3087	5–14
Logged (15) and burned (1)	1264.2 ± 866.3f	6.0 ± 7.3e	99.5	173–2191	0–17
d.f.	70	70			
F-ratio	24.9	7.0			
P	<0.0001	<0.0001			

Disturbance types are ordered according to increasing dominance of pioneers. Significant differences in pioneer and non-pioneer numbers (log transformed) between disturbance types (indicated with different characters) were tested using a general linear model with a Fishers' least significant difference test.

Since changes in forest structure and tree species composition after logging has become such a common and recurrent phenomenon in the lowland forests of East Kalimantan and in Southeast Asia in general (Slik & Eichhorn, 2003; Meijaard *et al.*, 2005), but very little is known regarding the effectiveness of commonly used SFM tools, I examined how forest structure as well as plant and bird species diversity are influenced by selective logging.

However, the discrimination between pioneer and climax species is not always that clear, since they each represent the extremes of a continuous life history gradient (Swaine & Whitmore, 1988; Slik *et al.*, 2003). In addition, the successional status of most species in selectively logged forest (in the process of being certified) is still largely unavailable, since the collection and management of such ecological data requires a lot of time and effort, and is therefore very expensive (Sheil, 1998).

Bird communities

Although logging forms a major threat to the last remaining patches of primary tropical lowland rainforest in Southeast Asia (Siegert *et al.*, 2001; Laurance, 2004), very few studies have thoroughly investigated the impact of logging on tropical bird communities in FSC certified forest concessions (Kinnaird & O'Brien, 1998; Haugaasen *et al.*, 2003; Barlow & Peres, 2004a), and our current understanding of bird community responses to logging is strongly geographically biased (Van der Hoeven *et al.*, 2000; De Iongh & Van Weerd, 2006). To be able to adapt bird conservation strategies to the growing expanses of secondary tropical lowland forest in Southeast Asia, more information about the impact of selectively logged forest on tropical bird communities is therefore urgently needed.

Bird species richness has been found to decline in response to logging (Johns, 1991; Thiollay, 1997; Marsden, 1998) but also to increase (Kofron & Chapman, 1995; Johns, 1996). Ghazoul and Hellier (2000) summarize bird species richness and abundance in primary forests (Table 1.3). After logging, avifaunal assemblages became increasingly dissimilar to primary forest and contained a higher abundance of species associated with second-growth habitats (Barlow & Peres, 2004a).

Table 1.3
Abundance of bird guilds (insectivore, frugivore and nectarivore) as a percentage of undisturbed forest values. Source: Ghazoul and Hellier (2000).

Site (Disturbance)	Insectivore	Frugivore	Nectarivore	References
Amazon (1-10 years)	7-28	47-63	65-90 n.s.	Thiollay, 1997
	25-66	58-67	57-100 n.s.	
Colombia (edges)	75	79	131	Restrepo & Gomez, 1998
Sabah (6-12 years)	72-105	100	100-129	Johns, 1996
	22-60	228	123	
Amazon (fragment)	–	–	267	Stouffer & Bierregaard, 1995
	42	61	137	
Amazon (11 years)	96	92	125	Johns, 1991
Uganda (5-40 years)	77	300	146	Owiunji & Plumptre, 1998
Sabah (8 years)	83	132	245	Lambert, 1992

These changes in avifaunal assemblages were strongly associated with changes in habitat structure, such as canopy cover and regeneration (Barlow & Peres, 2004b). In the Amazon region, most understorey insectivorous guilds declined, while arboreal nectarivores, granivores and frugivores became more abundant after the disturbance (Barlow & Peres, 2004a). A literature review by de Iongh

& Van Weerd (2006) confirmed that understorey insectivores were commonly affected by logging.

Overall, differences in bird species composition between secondary forests and primary forests are more pronounced when individual guilds are examined (Ghazoul & Hellier, 2000). The abundance of insectivorous birds, for example, generally declines in secondary habitats, while nectarivore abundance and species richness increases (Mason, 1996; Canaday, 1997). Thinning operations in particular, which are often carried out over large forest areas, cause considerable changes in the vegetation structure and the distribution of understorey insectivores (Waltert, 2000). In terms of SFM, avian guilds are therefore believed to provide an adequate measure for the long term conservation of forest habitats and their biodiversity (Parren & De Graaf, 1995).

Bird species diversity appears to be related to forest disturbance in a similar way, with a higher species diversity in logged forest and disturbed forest as compared to primary forest (Thiollay, 1992). Changes in bird diversity are most often due to loss of specialized bird species, which are replaced with more individuals of fewer (or more) generalist species (Devictor *et al.*, 2008; Kofron & Chapman, 1995). One of the characteristics of avian communities in tropical areas is the high number of species classified as endemics (Anderson, 1994; Stattersfield *et al.*, 1998; Boer, 2006). Endemic avian species diversity is highly sensitive to forest disturbance, such as logging (MacArthur & MacArthur, 1961; Henle *et al.*, 2004; Meijaard *et al.*, 2005). Meijaard *et al.* (2005) believe that there is an evolutionary explanation for the sensitivity of endemic bird species in Borneo to disturbance of forests, as these species have evolved in rainforest refugia during multiple ice-age cycles.

The various aspects of post-logging concession development have different impacts on habitats and the life-cycle of endemic bird species. As a group, birds are useful for evaluating the effects of logging on fauna, due to their well-established taxonomy and straightforward field identification characteristics, the availability of biological and ecological information on most bird families and many species, their apparent sensitivity to specific changes in forest structure, microclimate, composition and ecological role (e.g., pollination, seed dispersal and seed predation) (Fimbel *et al.*, 2001; Meijaard *et al.*, 2005). Meijaard *et al.* (2005) reported that birds typical of the canopy appeared to be more resilient, with the exception of the highly specialized Green Broadbill (*Calyptomena viridis*); i.e. frugivorous and nectarivorous species seldomly declined in logged forests. Groups that were affected by logging comprised of: 1) some extreme lowland specialist species, because logging in these forests is most intense (Black Hornbill *Anthracoceros*

malayanus, Crestless Fireback *Lophura erythrophthalma*); 2) nomadic species or species requiring large areas (hornbills, raptors); 3) primary forest species, intolerant to logging disturbance (Great Argus *Argusianus argus*, some trogons (*Harpactes* spp.), some woodpeckers (Picidae), some babblers (*Kenopia striata* and *Napothera* spp.) and some flycatchers (*Cyornis* spp. and *Ficedula* spp.); and 4) species that require large tree cavities for nesting. Among the most frequently used criteria for conservation priorities are so called hot spots of endemism; areas which are rich in range-restricted bird species that are threatened with extinction (Balmford, 2002; Myers *et al.*, 2000; Reid, 1998; Stattersfield *et al.*, 1998; Meijaard *et al.*, 2005). Meijaard *et al.* (2005) suggest that endemic species can provide a useful tool to monitor the effects of logging, due to their vulnerability to disturbance. It is therefore important to consider possible changes in the number of individuals of each endemic bird species, as well as their relative representations.

The impact of logging and forest fires in East Kalimantan

Mechanized logging and additional destructive activities have created large areas of secondary forest in Kalimantan (Slik *et al.*, 2002; Meijaard *et al.*, 2005). Pressure on the forests by mechanized logging and massive transmigration has strongly increased in East Kalimantan during the past decades (Kartawinata & Vayda, 1984; MacKinnon *et al.*, 1996). Before 1970, human impacts on the forest ecosystem in Kalimantan had been relatively limited. Shifting cultivation was practiced around the villages at a sustainable level due to low human population densities, and because technical equipment, such as chain saws, was often insufficient or had not yet been implemented for large-scale operations (Slik *et al.*, 2002). This situation changed with the introduction of mechanized logging and the arrival of transmigrants from Sulawesi and Java in the late 1960s and 1970s (Kartawinata & Vayda, 1984). Forest destruction by human activities was no longer compensated for by forest recovery, while activities of logging companies further intensified and the immigration of people continued. This gradual degradation of the forests was aggravated by the dramatic events of 1982–1983 and 1997–1998, when large tracks of forest burnt down as a result of "El-Niño" (Eichorn, 2003; Meijaard *et al.*, 2005), a significant periodical change in the warm ocean current, which had caused an exceptional drought in East Kalimantan. At that time, mechanized logging and additional destructive activities had created large areas of degraded rainforest which were highly susceptible to fire during dry periods (Cleary, 2002; Slik & Eichorn, 2003; Meijaard *et al.*, 2005; Eichorn *et al.*, 2006). These fires were repeated during the recent drought in 2015 as a result of severe drought caused by the El Niño Southern Oscillation (Marlier *et al.*, 2015).

Main aim and research questions of the thesis

The main aim of my research is to identify and analyze the impact of logging on plant and avian communities in East Kalimantan, Indonesia, in a forest concession which is in the process of FSC certification in Berau and two external sites (Sungai Wain and Pusrehut). Until now, no quantitative evidence on plant and bird communities has been assumed in the absence of sufficient quantitative scientific data (Van Kuijk *et al.*, 2009). My research covers plant and bird diversity and abundance in the selectively logged forest with different logging histories in the Berau district, the Sungai Wain protected forest and the Pusrehut forest. I defined the following research questions:

1 What are the differences in vegetation structure and composition in selectively logged forest sites in comparison to primary forest? (Chapter 2)
2 What are the differences in plant species diversity by diameter class and plant functional type between selectively logged forest sites in comparison to primary forest? (Chapter 3)
3 What are the differences in avian community composition and species abundance between selectively logged forest sites in comparison to primary forests? (Chapter 4)
4 What are the differences in endemic avian species diversity and abundance between selectively logged forest sites in comparison to primary forests? (Chapter 5)
5 What indicators could be identified for monitoring purposes?
6 Does the process of FSC certification contribute to biodiversity conservation?

Research location

Geographical location

The Province of East Kalimantan in Indonesia is part of the island of Borneo (Figure 1.1). It covers approximately 21,144 million ha, which is about 14% of the total Indonesian land surface. Geologically, East Kalimantan consists mainly of tertiary sedimentary rocks (Mantel *et al.*, 2002). The soils are Alisols, but in the extensive limestone areas North of Sangkulirang, they are classified as Luvisols (Van Bremen *et al.,* 1990). Local patches of coarse sandy soils (podzols) are found, covered with heath forest (Kerangas). The province of East Kalimantan encompasses a variety of forest types comprising primary forest, secondary forest, mangrove forest, swamp forest, peat swamp forest, logged over forest and heath forest, stretching from sea-level up to 3,000 m elevation (Whitemore,

1984). Most of the remnant primary forest is characterized by an elevation up to 1,000 m above sea-level, although some mountainous ranges located above 1500 m can be found in the western part of the province. This combination of forest types has been well described for the Bornean provinces of Sarawak and Sabah (Whitemore, 1984).

The botanical diversity of Borneo is illustrated by the 84 families and 370 genera comprising at least one big tree species each (defined as either 35 cm dbh or over 20 m tall) listed by Whitmore *et al.* (1990). Ashton (1989) gives an estimate of 10,000-15,000 species of higher plants (spermatophytes) and states that the flora of Borneo and especially the province of Kalimantan is still under-collected. The botanic taxonomical surveys for Borneo by Sidiyasa *et al.* (1999) since 1991 up to April 1999 have added 181 families, 888 genera and 1,911 species to the collections of Kalimantan. These collections comprise mainly trees from the Balikpapan-Samarinda area.

Study sites

My research was carried out in three main study sites (Figure 1.1): 1) In the district of Berau in selectively logged forest sites, in PT. Hutansangam Labanan Lestari (PT.HLL), East Kalimantan. The largest share of the new company area belongs to the state-owned logging company of PT. Inhutani I, a forest concession in the process of FSC certification, 2) in the district of Balikpapan in the Sungai Wain protected forest, and 3) in the district of Kutai Kartanegara in the Pusrehut forest ex-logging concession. These study sites were each divided into different forest types as follows: i) In the district of Berau four sites were established; in primary forest (1 site) and selectively logged forest (3 sites), ii) in the district of Balikpapan in Sungai Wain protected forest only primary forest was sampled (1 site), and iii) in the district of Kutai Kartanegara I sampled an ex logging concession in the Pusrehut forest (1 site). These are the areas where semi-permanent plots had been surveyed for plant and bird diversities.

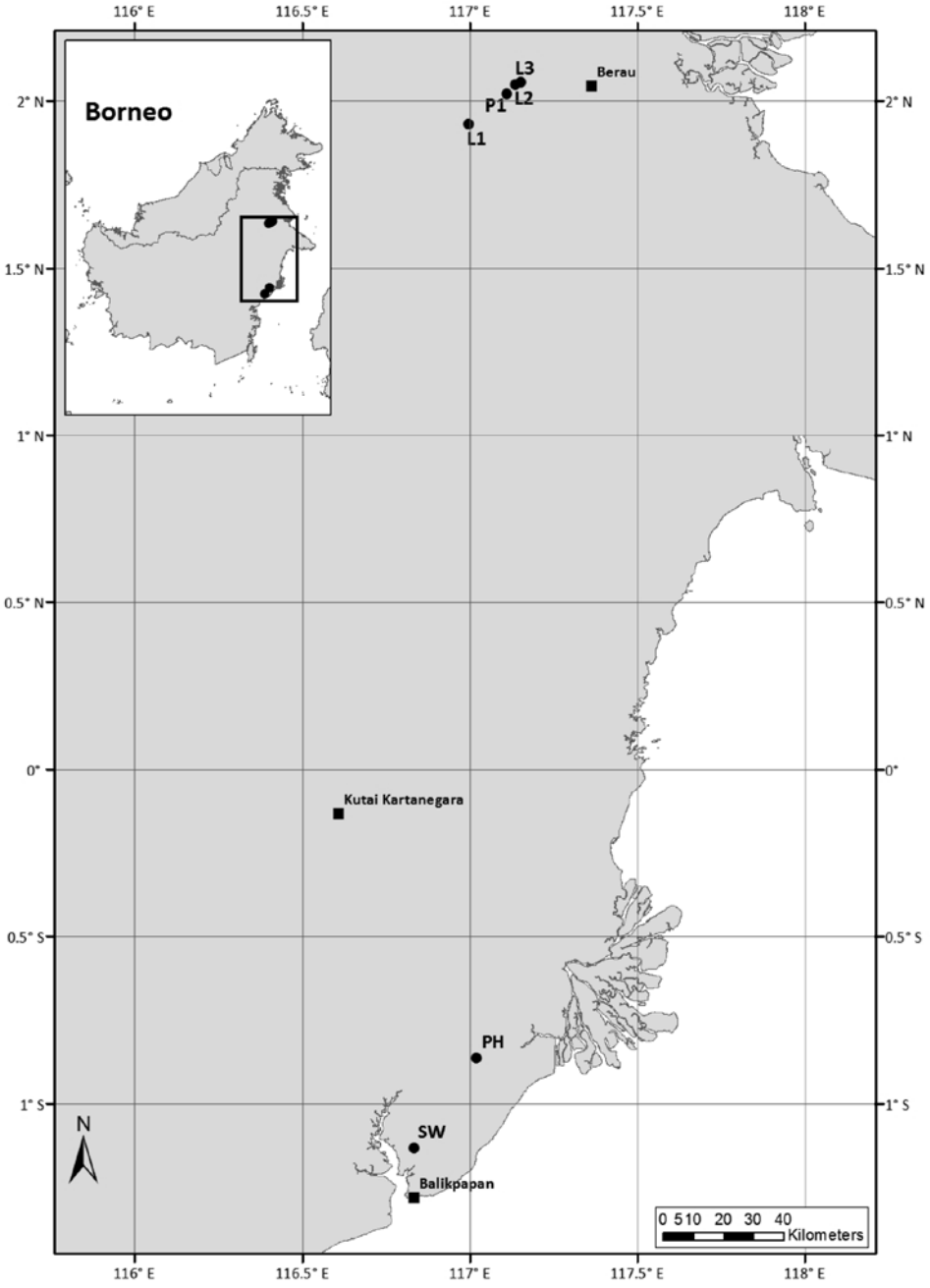

Figure 1.1
Map of East Kalimantan with the location of sampling points. P1 = primary forest site, L1 = logged in 2011, L2 = logged in 2007, L3 = logged in 2003, SW = Sungai Wain protected forest site (primary forest), PH = Pusrehut forest site (disturbed forest).

Berau district

The Berau District is located in the northeastern part of East Kalimantan Province. It covers approximately 2,558,205 ha. The location is between 1°45'-2°10'north latitude and 116°55'- 117°20'east longitude (Fauzi, 2001). The total human population size of the Berau District is 179,444. The Berau District is divided into 13 sub-districts (http://id.wikipedia.org/wiki/Templat:Kabupaten_Berau). The study area is located in a lowland forest within the forest concession of PT. Hutansanggam Labanan Lestari (HLL) Labanan, East Kalimantan. The largest share of the new company area belongs to the state-owned logging company of PT. Inhutani I, which is one of the logging companies which have obtained FSC Certification for some concessions. PT. Inhutani I, Berau, East Kalimantan, is another one the process of FSC Certification (http://mutucertification.com/en /10-perusahaan-kehutanan-daftar-proses-sertifikasi-fsc).

Logging concession in Labanan

As mentioned, my study area is in the process of FSC certification. During the actual certification process, the logging concession in Labanan Forest Management Unit (FMU) is still a part of PT. Inhutani I (see Figure 1.1) is a government enterprise that is owned by the Ministry of Finance (Wardana, 2002). PT. Inhutani I obtained the concession, comprising a total area of 2.2 million hectares in 1976. In 1995, after a first concession period of about 20 years the Ministry of Forestry (MoF) extended the concession for the second period and the area was reduced to 1,185,249 hectares. The concession was divided into two units: Unit I Balikpapan area, which covers 444,133 ha and Unit II Tarakan area, which covers 741,116 ha. The Balikpapan Unit I was a controlled forest management unit with six plots, one of which (Labanan) covered 83,240 ha (Purbawiyatna, 2002). In April 2000, the director of PT. Inhutani I established the Labanan forest management unit as a self-managed unit. Within this unit, the effective area for timber production is about 63% of the total area; the remaining area was excluded from production, in consideration of other purposes. This excluded area consists of a transmigration area (1,978 ha), a community forest (7,122 ha) and a protection area (15,945 ha) according to Kuswandari (2004).

In the Labanan FMU several forest research projects have been carried out during the past decades, either by local institutions or under inter-governmental-collaboration, e.g. with the International Technological Center-ITC in Enschede, The Netherlands (Kuswandari, 2004). From 1989 until 1996, the STREK programme (Silvicultural Techniques for the Regeneration of logged over forest in East Kalimantan) focused on the development of sylvicultural and management

rules leading to sustained productivity of the forest in East Kalimantan. The project was carried out under the authority of MoF through the Forestry Research and Development Agency and PT. Inhutani I with the assistance of CIRAD-forest (Fauzi, 2001). From 1996 to 2003, the Berau Forest Management Project (BFMP), led by MoF and the European Union aimed at developing, testing and promoting a replicable example of sustainable forest management at operational level. To support this project, the Ministry of Forestry and Estates designated the Labanan FMU as a special status area under decree No. 866/Kpts-II/1999 (Kuswandari, 2004).

Sungai Wain protected forest

The Sungai Wain protected primary forest (116.49 E, 1.06 S) is a water catchment area for the city of Balikpapan (Fredriksson & De Kam, 1999). It originally comprised c. 10,000 ha of Mixed Dipterocarp Forest (MDF). About half of the total area was burnt during the first half of 1998, while a central core area was protected from fire by the establishment of firebreaks. In this reserve, plant diversity was studied in unburnt and once-burnt forest (following Eichhorn *et al.*, 2006). The unburnt forest site was located in the central core area and had a very similar tree composition as other MDF in this region (Van Nieuwstadt, 2002; Slik *et al.*, 2003; Eichhorn *et al.*, 2006). The once-burnt forest site is located in the north-western part of the reserve. It was heavily damaged by the fires over most of its area, as could be concluded from the very few stems that survived the fires (Van Nieuwstadt *et al.*, 2001). This study site was therefore classified as having total fire damage, the most severely affected category of burnt forests (Siegert *et al.*, 2001). Despite being heavily affected, the area has been strictly protected since 2001, which allowed the forest to restore considerably, especially in the core area.

Pusrehut forest

The Tropical Rain Forest Research Center (Pusat Studi Reboisasi Hutan Tropika Humida; PUSREHUT) has become a center for studies on forest rehabilitation for many scientists from several countries, with a field station where students from multiple nationalities have conducted their academic studies. Mulawarman University (Universitas Mulawarman; UNMUL) at Samarinda, the capital of East Kalimantan, is one of the National Public Universities which was founded in the early 1970s. A priority in research at this university is research on the rehabilitation of tropical rainforest. As a result of the involvement of the Japan International Cooperation Agency (JICA), in 1979 the Tropical Rain Forest Research Center was jointly established in East Kalimantan. Most of the Research

Center's forest consists of planted trees of *Dipterocarpaceae pp*. species and fruit tree species.

Thesis outline

The thesis comprises six chapters as follows: Chapter 1 provides a general introduction and review of the study topic. It presents the research questions to be addressed and describes the study sites. Chapter 2 deals with structure, composition and diversity of plant communities in FSC-candidate, selectively logged forests of different ages compared to primary rainforest. In this Chapter I examine the structure and composition of forest plots under different logging regimes by assigning species to life forms. Chapter 3 discusses plant communities in FSC-candidate, selectively logged forests compared to primary forest in relation to stem diameter and plant functional types. In Chapter 4 I elaborate on the response of avian communities to FSC-candidate logging in East Kalimantan. Chapter 5 specifies the impacts of FSC-candidate logging in tropical lowland rainforest on endemic Bornean avian species. Chapter 6 provides a general discussion and conclusive remarks on my findings and other available plant and bird data from FSC-candidate selectively logged forest sites of different regime histories. I further formulate recommendations on how these data could be applied to future efforts in the field of plant and bird conservation.

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Structure, composition and diversity of plant communities, selectively logged forests of different ages compared to primary rain forest

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Arbainsyah, H.H. de Iongh, W. Kustiawan & G.R. de Snoo

Abstract

The impact of logging on plant communities was studied in forest that has been logged selectively 1, 5 and 10 years previously (in the process of certified): diversity was compared with that of primary rain forest in the Berau region of East Kalimantan, Indonesia. Four sets of 20 transects located within an area of 6 ha were sampled for all trees, saplings and seedlings, and records were made of topographic position, structure, composition and species diversity. There was a high level of floristic similarity between primary forests at the study sites compared to primary forest elsewhere in Kalimantan. The impact of logging is therefore likely to be the most important factor determining any differences between the plant communities of the selectively logged and primary forest sites. We found differences in species composition and abundance of most plants between selectively logged and primary forest. Overall, stem densities of trees in the primary forest were higher than in the three selectively logged forest sites. Stem densities of saplings were equivalent in all four forests. Seedling stem densities were higher in the forest site logged 10 years previously than in primary forest. Our results showed that the forests logged selectively under certified regimes still have a high plant diversity, possibly indicating that biodiversity values may be conserved by following certification procedures.

Key words: Sustainable forest management, Selective logging, Species diversity, Forest structure, Tropical rain forest.

Introduction

Tropical rain forests are recognized for their high biological diversity and their ecosystem services (Richards, 1952; Whitmore, 1984; Sheil & Van Heist, 2000; Jennings *et al.*, 2001). Large parts of East Kalimantan are now covered by forests that are degraded as a result of fire and logging (Slik *et al.*, 2002; van Nieuwstadt 2002; Meijaard *et al.*, 2005; Eichhorn *et al.*, 2006). Forest certification (Lembaga Ekolabel Indonesia-LEI and the Forest Stewardship Council-FSC) has been introduced in Indonesia since several decades. The impact of FSC-certified logging on biodiversity has rarely been quantified, however (Van Kuijk *et al.*, 2009). There is a need to develop suitable biological indicators of sustainable forest management at the forest management unit level (Ghazoul & Hellier 2000; De Iongh & Van Weerd, 2006; De Iongh & Persoon, 2010).

Commercial logging leads to fragmentation and degradation of the remaining tropical rain forests (Kartawinata, 1977; Skole & Tucker, 1993; Parthasarathy *et al.*, 1999), and results in many processes negatively affecting populations of plants and animals. When basic biological characteristics of the commercial species are considered in timber harvesting prescriptions, mixed dipterocarp forests appear capable of sustained timber yield in combination with habitat conservation. The Indonesian selective logging system allow selective logging intensity of ≥ 8 trees/ha associated with a felling cycle of 40–60 years depending on site conditions (Sist *et al.*, 2003; Van Kuijk *et al.*, 2009). It has been more than 10 years since parts of the forest were selectively logged in the initial exploitation period in the 2000s (Kuswandari, 2004). Intermediate disturbance hypothesis is one of the most frequently suggested non-equilibrium explanations for maintaining species diversity in all communities (Connell, 1978; Wilson, 1990; Roxburgh *et al.*, 2004).

Tree mortality in the understorey of logged forest is at least 2–3 times lower than in the forest overstorey, and mostly occurs near and on skid trails (Webb, 1998; Woods, 1998; Pinard *et al.*, 2000; Slik *et al.*, 2002). In addition, some light-demanding, non-pioneer species may exhibit higher growth rates after logging. The increased light levels in the understorey of logged forests result in the rapid growth of many herbaceous and woody pioneer species (Woods, 1998; Fredericksen & Mostacedo, 2000). Trees make up only a part of the tropical rain forest ecosystem; herbs, shrubs, ferns and lianas generally constitute a large component of total plant diversity (Eichhorn *et al.*, 2006; Yassir *et al.*, 2010). To evaluate its biodiversity it is very important to know the vegetation composition of a forest type, from canopy to forest floor including trees, climbers (liana and rattan),

non-rattan (Palmae), herbs, shrubs, etc., all of which are genetic resources for plant species within the forest.

Many impacts of logging have been studied; tree mortality in the forest overstorey (diameter at breast hight (dbh) ≥ 10 cm) (Slik *et al.*, 2002; Van Nieuwstadt, 2002), the mortality of canopy trees due to edge effects (Laurance et al. 2000), recruitment failure resulting from over-predation of seeds (Curran *et al.*, 1999; Eichhorn *et al.*, 2006), reduced seedling establishment and plant growth (Slik, 2001; Bruna *et al.*, 2002; Bruna, 2003), local extinction of plants (Benitez-Malvido & Martinez-Ramos, 2003), decline in butterfly abundance and/or diversity (Cleary, 2002), decline in bird abundance and/or diversity (Boulinier *et al.*, 2001; Beier *et al.*, 2002; Slik & Van Balen 2006), and decreased pollination (Ashworth *et al.*, 2004). Logging also often leads to an increase in local human populations and to increased accessibility of the forest (Kartawinata & Vayda, 1984), which in turn results in increased illegal logging and hunting and a decrease in biodiversity of remaining forest fragments (Laurance, 1998; Hartshorn & Bynum, 2001; Curran *et al.*, 2004). The final outcome may be local mass extinctions of species as has been recently documented for Singapore (Brook *et al.*, 2003). Because tropical rain forests harbour most of the world's biodiversity, tropical deforestation has become the major cause of global species extinctions (Pimm & Raven, 2000).

The main goal of our research is to quantify the impact of selectively logged forest in the process of FSC certification on botanic diversity and forest structure of tropical lowland forest in Borneo. Here we present the results of a detailed study of selectively logged forests (in the process of FSC certification) and primary rain forest site in the Indonesian province of East Kalimantan, including all terrestrial vascular plants. The three logged forest plots had been logged 1, 5 and 10 years ago. We analysed the structure and composition of forest plots under different logging regimes by assigning species to life forms that can be readily applied in the field (e.g., Eichhorn *et al.*, 2006). We assessed the impact of selective logging at the landscape level to ensure that our plant diversity assessment was representative for the large scale at which disturbance by logging activities occurs. The numbers were expected to reflect the scale and severity of the disturbances taking place in a large forest area (Primack & Lee, 1991; Davies *et al.*,1998; Slik *et al.*, 2002), and as such could be useful to estimate the impact of logging on future plant diversity. Finally, we address what are the differences in vegetation structure and composition in selectively logged forest sites in comparison to primary forest?

Materials and methods

Study area

The study area is located in a lowland forest within the forest concession of PT. Hutansanggam Labanan Lestari (HLL) Labanan, East Kalimantan. The largest share of the new company area belong to the state-owned logging company of PT. Inhutani I (in the process of FSC certification), in Berau district, in the northeastern part of the Indonesian province of East Kalimantan (Figure 2.1). This concession is in the process of being FSC certified. The elevation range at the study area is 25 to 140 m above sea level. The topography consists of a rolling hilly landscape with shallow valleys and gullies, the highest elevation being 140 m. The soils consist of loamy clay and sandy soils with a top soil layer of approximately 5-10 cm (Mantel *et al.*, 2002).

Sites were established in primary forest (1 site) and selectively logged forest (3 sites) (Figure 2.1). In these plots, three groups of plants (trees, saplings and seedlings) were systematically recorded along a line transect of 10 × 300 m. In total, 20 transects were sampled, 5 in primary forest and 5 in each of the 3 selectively logged over forest. We divided each line transect into 30 plots of 10 × 10 m (a total of 150 plots in each site) to measure all trees with a dbh ≥ 10 cm (dbh. 130 m above ground level or, if buttresses are present, 30 cm above buttresses) using the circumference method. Within each plot, a subplot of 5 × 5 m for saplings and 2 × 2 m for seedlings were established and measured (number of individuals per species and cover estimate). These measurement quadrats for seedlings and saplings were positioned alternately to the left and right of transect centre lines at intervals of 100 m, resulting in 15 subplots per site.

Plants were sampled and identified, i.e. whenever a fertile plant, labeled (vouchers stored in the Herbarium Wanariset Samboja, Indonesia). The field work was done by the principle author, together with field assistants.

Life forms

In order to provide a detailed description of the structure and composition of the terrestrial plant community in the four research sites, all species were assigned to life forms and taxonomic criteria (Table 2.1). The criteria used were chosen in such a way that they provided maximum information about the forest structure and composition while still being applicable for para-taxonomists in comparative studies in East Kalimantan and elsewhere in the tropics (Eichhorn *et al.*, 2006). To enhance compatibility with growth forms that were used in similar studies

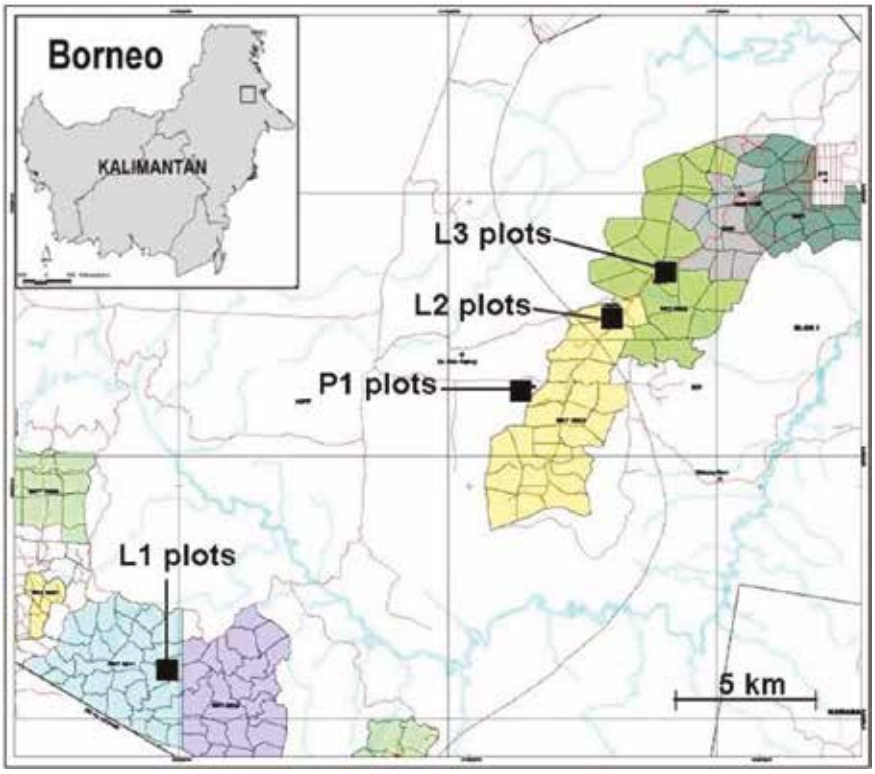

Figure 2.1
Map of East Kalimantan with the location of study areas P1 plots: primary forest site, L1 plots: forest site logged 1 year ago (2011), L2 plots: forest site logged 5 years ago (2007), L3 plots: forest site logged 10 years ago (2003).

in the past, species were first assigned to three major groups: trees, saplings and seedlings. Several life forms were distinguished within these three major groups, based on taxonomic criteria and growth form. Throughout this study, each plant species was assigned referred to one of the following three life forms.

1. *Trees* defined as non-climbing woody species of which the mature individuals had a stem diameter ≥ 10 cm.
2. *Saplings* defined as all herbaceous species, non-climbing woody species and climbing woody species of which the mature individuals had a stem diameter ≤ 10 cm and were on average more than 1.5 m tall.
3. *Seedlings* defined as all herbaceous species, non-climbing woody species and climbing woody species of which the mature individuals were on average less than 1.5 m tall.

Table 2.1
List of the life forms used in this study and the taxa, growth form and size class they represent.

Life Form	Taxa	Growth form and size
Trees (woody non-climbers with stem diameter ≥ 10 cm)		
Palms - trees	Palmae	woody non climbers, height >1.3 m
Dicots – trees	Dicotyledonae	woody non climbers, height >1.3 m
Saplings (herbs, shrubs, climbers, woody non-climbers with diameter < 10 cm)		
Monocots - other herbs	Monocotyledonae	herbaceous non climbers, height >1.5 m
Dicots - trees	Dicotyledonae	woody non climbers, height >1.5 m
Dicots - lianas	Dicotyledonae	climber, height >1.5 m
Dicots - shrubs	Dicotyledonae	woody non climbers, with many branches from the ground, height >1.5 m
Seedlings (herbs, shrubs, climbers, woody non-climbers < 1.5 height		
Palms - lianas (rottans)	Palmae	climber, height <1.5 m
Palms - palmlets	Palmae	woody non-climber, height <1.5
Monocots - small lianas	Monocotyledonae	climber, height <1.5 m
Monocots - other herbs	Monocotyledonae	herbaceous non climbers
Monocots - grass-like	Graminae+Cyperaceae	herbaceous, leaves linear
Dicots - small treelets	Dicotyledonae	woody non-climber, height <1.5
Dicots - small lianas	Dicotyledonae	climber, height <1.5 m
Dicots - small shrubs	Dicotyledonae	woody non-climber, with many branches from the ground, height <1.5
Ferns - small lianas	Filicopsida	climbers
Ferns - herbs	Filicopsida	herbaceous non climbers

Data analyses and statistics

All data analyses were performed with Microsoft Excel and SPSS 13.0 software to calculate standard deviation for the estimated average number of stems. Tree species diversity of the plots was compared between of selectively logged forests, and primary forest. These comparisons were made to compensate for differences in sample sites between of selectively logged forests in comparison to primary forest. Post hoc comparisons between of selectively logged forests, and primary forest were made using the Fisher's Least Significant test (one-way ANOVA based on ln transformed data, with Bonferroni multiple comparison test). The stages in evaluating the data were as follows:

1 Counting the number of stems of all trees, saplings and seedlings found in each transect.

2 Calculating Species Diversity Index (H), Evenness Index (E) and Dominance Index (C).
Species diversity analysis was done with the Shannon Diversity Index, with the Jost (2006) formula as follows:

Diversity Index $$H = \sum_{S=1}^{S} p_i \ln p_i$$

where H is the Shannon Diversity Index, S is the total number of species in the community, pi is the proportion of abundance of the i species. pi is calculated by dividing the number of species i by the total number of all species. Then to determine the Evenness Index (E) the Pielou Evenness Index (Ludwig & Reynolds, 1998) formula was used:

$$\text{Evenness Index (E)} = \sum H/\ln(S)$$

where E is the Pielou Evenness Index, ln is the normal logarithm, S number of species.
The Dominance Index (C) was determined using the formula:

$$\text{Dominance Index (C)} = \sum (ni/N)^2$$

where C is the Dominance Index, ni is the number of individuals of a certain species, N is the total number of individuals of all species.

3 Calculating the estimated average number of stems (N) and stems per hectare (q) for each class (trees, saplings and seedlings) Ludwig and Reynolds (1998):

$$q = \frac{\sum_{i=1}^{n} Yi}{\sum_{i=1}^{n} Xi}$$

where q is the average number of stems (N) per hectare, Yi is the Number of stems (N) per hectare of given transect, Xi is the area of a given transect.

4 Calculating the Importance Value index (I.V.) for each level/strata. The formula used in calculating I.V. was the quadrate method (Mueller-Dombois & Ellenberg, 1974). The (I.V.) of species is defined as sum of its relative density

(RD), relative dominance (Rd) and relative frequency (RF) (I.V.) = RD + RF + Rd), which are calculated using the following equations:

$$\text{Density (D)} = \frac{\text{Number of individuals of a species}}{\text{Area of all sample units}}$$

$$\text{Relative Density (RD)} = \frac{\text{Number of individuals of a species}}{\text{Density for all species}} \times 100\%$$

$$\text{Frequency (F)} = \frac{\text{Number of quadrats containing a certain species}}{\text{Total number of quadrats}}$$

$$\text{Relative Frequency (RF)} = \frac{\text{Frequency of a certain species}}{\text{Total number of species}} \times 100\%$$

$$\text{Dominance (d)} = \frac{\text{Basal area of a species}}{\text{Area of all sample units}}$$

$$\text{Relative Dominance (Rd)} = \frac{\text{Dominance of one species}}{\text{Dominance of all species}} \times 100\%$$

The Importance Value index for trees and saplings was calculated based on the formula:

$$\text{Importance Value index (I.V.)} = RD + RF + Rd$$

For seedling levels, the species importance value index was calculated using the formula:

$$\text{Importance Value index (I.V.)} = RD + RF$$

Results

Composition and biodiversity in selectively logged and primary forests

Tree diversity was higher in the forest site logged selectively 1 year ago, where $H > 4.5$, but the dominance index and number of stems were almost as high in the primary forest site (Table 2.2). This high dominance index is indicated by the very abundant tree species of *Hopea semicuneata*, with an I.V. score of 43.4% (Table 2.6). In contrast to the tree diversity index, the highest evenness index was

found in the forest site logged 1 year ago, with a total of 156 species encountered (Table 2.3).

Sapling diversity was higher in the primary forest site compared to selectively logged forest sites, but the dominance index of the forest site logged 5 years ago was higher than that of the other forest sites (Table 2.2). This high dominance is indicated by regenerating species of *Madhuca malaccensis*, with an I.V. score of 25.5%, two times more dominant than other species (Table 2.7). In contrast to the saplings diversity index, the highest evenness index was found in primary forest with a total number of 97 species encountered (Table 2.4).

Seedling diversity was high in some of the selectively logged forest sites, in the forest site logged 1 year ago, but due to the dominance index was found in primary forest site (Table 2.2). This dominance was indicated by the very abundant species of *Hopea semicuneata,* with an I.V. score of 24.6%, which is also the highest in the regeneration of saplings and trees (Table 2.7 and 2.8). In contrast to the seedlings diversity index, the highest evenness index was found in the forest site logged 1 year ago, with a total number of 95 species encountered (Table 2.5).

Table 2.2
Comparison between the diversity index (H), dominance index (C), evenness index (E) and number of stems for all trees (dbh ≥ 10 cm) per 1.5 ha, all saplings (dbh < 10 cm) per 0.375 ha and all seedlings in ground cover per 0.06 ha in primary forest site and three selectively logged forest: logged 1 year ago, logged 5 years ago and logged 10 years ago.

Index	Primary forest	Selectively logged Forest		
		1 year ago	5 years ago	10 years ago
Tree (1.5 ha)				
▪ Diversity (H)	4.259	4.509	4.339	4.260
▪ Dominance (C)	0.033	0.019	0.023	0.022
▪ Evenness (E)	0.853	0.893	0.879	0.888
▪ Number of stems	612	492	501	558
Sapling (0.375 ha)				
▪ Diversity (H)	4.352	4.175	4.095	4.150
▪ Dominance (C)	0.015	0.020	0.024	0.023
▪ Evenness (E)	0.951	0.937	0.922	0.918
▪ Number of stems	245	247	242	244
Seedling (0.06 ha)				
▪ Diversity (H)	4.067	4.319	4.090	4.217
▪ Dominance (C)	0.030	0.017	0.025	0.020
▪ Evenness (E)	0.908	0.948	0.913	0.930
▪ Number of stems	328	306	303	346

Table 2.3
Comparison between the abundance and species richness (average ± standard deviation) for all trees (dbh ≥ 10 cm) life form and forest sites.

Trees	Abundance stems (per 100 m²)				Species per subplot (10 × 10 m)				Total species number			
	Primary forest	Selectively logged forest			Primary forest	Selectively logged forest			Primary forest	Selectively logged forest		
		1 year ago	5 years ago	10 years ago		1 year ago	5 years ago	10 year ago		1 years ago	5 years ago	10 years ago
Life form												
▪ Palms - trees	0.00 ± 0.00	0.05 ± 0.29	0.00 ± 0.00	0.02 ± 0.25	0.00 ± 0.00	0.04 ± 0.19	0.00 ± 0.00	0.01 ± 0.08	0	1	0	1
▪ Dicots - trees	4.08 ± 1.97	**3.23 ± 2.13**	**3.34 ± 2.08**	3.70 ± 1.86	3.70 ± 1.78	3.30 ± 1.67	3.19 ± 1.79	3.49 ± 1.62	147	155	139	120
Total	4.08 ± 1.97	**3.28 ± 2.15**	**3.34 ± 2.08**	3.72 ± 1.87	3.70 ± 1.78	3.33 ± 1.70	3.19 ± 1.79	3.49 ± 1.62	147	156	139	121

Abundance expressed as densities of stems exceeding 1.3 height. Species richness at the subplot scale expressed as species number per subplot and at the landscape scale as the total observed species numbers in all subplot together in primary forest site and three selectively logged forest: logged 1 year ago, logged 5 years ago and logged 10 years ago, in plot of 10 × 10 m, in total of 1.5 ha. **Bold** averages for selectively logged forest sites differ significantly from those of the primary forest site (with Bonferroni correction for multiple tests)

Table 2.4
Comparison between the abundance and species richness (average ± standard deviation) for all saplings (dbh < 10 cm) life form and forest sites.

Saplings	Abundance stems ((per 25 m²)				Species per subplot (5 x 5 m)				Total species number			
	Primary forest	Selectively logged forest			Primary forest	Selectively logged forest			Primary forest	Selectively logged forest		
		1 year ago	5 years ago	10 years ago		1 year ago	5 years ago	10 years ago		1 years ago	5 years ago	10 years ago
Life form												
▪ Monocots - herbs	0.00 ± 0.00	0.13 ± 0.52	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.07 ± 0.26	0.00 ± 0.00	0.00 ± 0.00	0	1	0	0
▪ Dicots - treelets	16.27 ± 4.11	15.80 ± 6.19	15.40 ± 5.26	15.60 ± 3.58	12.93 ± 3.01	9.40 ± 3.14	11.93 ± 4.20	10.40 ± 4.10	96	83	84	89
▪ Dicots - lianas	0.00 ± 0.00	0.40 ± 1.55	0.00 ± 0.00	0.33 ± 1.29	0.00 ± 0.00	0.07 ± 0.26	0.00 ± 0.00	0.13 ± 0.52	0	1	0	2
▪ Dicots - shrubs	0.06 ± 0.26	0.13 ± 0.35	0.73 ± 1.16	0.33 ± 0.72	0.07 ± 0.26	0.13 ± 0.35	0.40 ± 0.51	0.20 ± 0.41	1	1	1	1
Taxa												
▪ Monocots	0.00 ± 0.00	0.13 ± 0.52	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.07 ± 0.26	0.00 ± 0.00	0.00 ± 0.00	0	1	0	0
▪ Dicots	16.33 ± 4.06	16.34 ± 6.35	16.13 ± 5.88	16.27 ± 4.37	13.00 ± 2.98	9.60 ± 3.18	12.27 ± 4.40	10.73 ± 4.04	97	85	85	92
Total	16.33 ± 4.07	16.47 ± 6.50	16.13 ± 5.88	16.27 ± 4.37	13.00 ± 2.98	9.67 ± 3.13	12.27 ± 4.40	10.73 ± 4.04	97	86	85	92

Abundance expressed as densities of stems exceeding ≥ 1.5 height. Species richness at the subplot scale expressed as species number per subplot and at the landscape scale as the total observed numbers of species in all subplots together in primary forest site and three selectively logged forest: logged 1 year ago, logged 5 years ago and logged 10 years ago, in plot of 5 x 5 m, in total of 0.375 ha. **Bold** averages for selectively logged forest sites differ significantly from those of the primary forest site (with Bonferroni Correction for multiple tests).

Table 2.5
Comparison between the abundance and species richness (average ± standard deviation) for all seedlings life form and forest sites.

Seedlings	Abundance stems (per 4 m²)				Species per subplot (2 × 2 m)				Total species number			
	Primary forest	Selectively logged forest			Primary forest	Selectively logged forest			Primary forest	Selectively logged forest		
		1 year ago	5 year ago	10 year ago		1 year ago	5 year ago	10 year ago		1 year ago	5 years ago	10 years ago
Life form												
▪ Palms - lianas (rottans)	0.80 ± 1.21	0.27 ± 0.46	0.13 ± 0.35	0.13 ± 0.35	0.53 ± 0.74	0.27 ± 0.46	0.13 ± 0.35	0.13 ± 0.35	3	2	2	2
▪ Palms - small trees	0.13 ± 0.52	0.07 ± 0.26	0.00 ± 0.00	0.00 ± 0.00	0.07 ± 0.26	0.07 ± 0.26	0.00 ± 0.00	0.00 ± 0.00	1	1	0	0
▪ Monocots- small lianas	0.07 ± 0.26	0.07 ± 0.26	0.00 ± 0.00	0.00 ± 0.00	0.07 ± 0.26	0.07 ± 0.26	0.00 ± 0.00	0.00 ± 0.00	1	1	0	0
▪ Monocots - herbs	0.07 ± 0.26	0.33 ± 0.72	0.67 ± 1.84	0.13 ± 0.35	0.07 ± 0.26	0.20 ± 0.41	0.20 ± 0.41	0.13 ± 0.35	1	2	2	2
▪ Monocots - grass	0.20 ± 0.56	0.53 ± 1.19	0.00 ± 0.00	0.13 ± 0.52	0.13 ± 0.35	0.27 ± 0.59	0.00 ± 0.00	0.07 ± 0.26	2	2	0	1
▪ Dicots - small trees	18.80 ± 9.22	12.87 ± 6.86	15.80 ± 8.05	18.60 ± 9.91	8.33 ± 2.32	6.87 ± 3.16	8.13 ± 2.64	8.40 ± 3.58	69	67	65	75
▪ Dicots - small lianas	1.67 ± 1.95	**3.33 ± 3.54**	1.93 ± 1.39	**0.80 ± 1.26**	1.00 ± 1.00	**1.47 ± 0.99**	**1.47 ± 1.13**	**0.47 ± 0.74**	9	13	15	6
▪ Dicots - shrubs	0.07 ± 0.26	0.47 ± 0.92	0.13 ± 0.52	0.27 ± 0.46	0.07 ± 0.26	0.20 ± 0.41	0.07 ± 0.26	0.27 ± 0.46	1	3	1	1
▪ Ferns - small lianas	0.07 ± 0.26	0.60 ± 1.59	1.47 ± 3.09	1.20 ± 2.78	0.07 ± 0.26	0.13 ± 0.35	0.20 ± 0.41	0.40 ± 0.83	1	1	2	4
▪ Ferns - herbs	0.00 ± 0.00	1.67 ± 2.23	0.07 ± 0.26	1.80 ± 4.18	0.00 ± 0.00	**0.60 ± 0.74**	**0.07 ± 0.26**	0.27 ± 0.59	0	2	1	2
▪ Ferns - small trees	0.00 ± 0.00	0.20 ± 0.41	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.20 ± 0.41	0.00 ± 0.00	0.00 ± 0.00	0	1	0	0
Taxa												
▪ Monocots	1.27 ± 1.39	1.27 ± 1.28	0.80 ± 1.86	0.40 ± 0.74	0.87 ± 0.83	0.87 ± 0.74	0.33 ± 0.62	0.33 ± 0.62	9	8	4	5
▪ Dicots	20.53 ± 8.83	16.67 ± 8.80	17.87 ± 8.24	19.67 ± 9.82	9.40 ± 2.47	8.40 ± 3.91	9.67 ± 2.58	9.13 ± 3.64	78	83	81	82
▪ Ferns	0.07 ± 0.26	2.47 ± 2.83	1.53 ± 3.20	3.00 ± 6.89	0.07 ± 0.26	**1.07 ± 0.96**	0.27 ± 0.59	0.67 ± 1.40	1	4	3	6
Total	21.87 ± 8.84	20.40 ± 9.82	20.20 ± 6.46	23.07 ± 11.20	10.33 ± 2.64	10.33 ± 4.27	10.27 ± 2.34	10.13 ± 3.09	88	95	88	93

Abundance expressed as densities of stems percentage ground cover. Species richness at the subplot scale expressed as species number per subplot and at the landscape scale as the total observed species numbers in all subplot together in primary forest site and three selectively logged forest: logged 1 year ago, logged 5 years ago and logged 10 years ago, in plot of 2 x 2, in total of 0.06 ha. **Bold** averages for selectively logged forest sites differ significantly from those of the primary forest site (with Bonferroni correction for multiple tests).

Abundance and composition of three major groups of species

Tree densities were significantly lower in the forest sites logged selectively 1 and 5 years ago than in the primary forest site, but tree densities in the forest site logged 10 years ago were similar to those of the primary forest site (Table 2.3). Dicot trees were clearly the dominant tree type, as they accounted for ca. 99% of the stems in all four forest sites. However, palm trees still exceeded densities of 3 stems ha^{-1} in at least one of the four forest sites.

There were no significant differences in sapling densities among all four forests, but due to the dicot shrubs, the total number of stems in the forest site logged 5 years ago was higher than in the other three forest sites (Table 2.4). When the dicot shrubs were excluded from the analysis, stem density in the selectively logged forest, namely of the forest site 5 years ago was 242 stems ha^{-1} this is the lowest when compared to primary forest site, the sites logged 1 year ago and 10 years ago with stem density of 245, 247 and 244 stems ha^{-1}.

There were no significant differences between seedlings, which were in general equally abundant in all four forest sites. Due to the presence of small dicot lianas, the total number of stems in forest sites logged selectively 1 and 10 years ago was significantly greater than in the other forest sites (Table 2.5). Palm lianas were clearly the most abundant life form in primary forest, while small fern lianas and fern herbs were both very abundant in selectively logged forest sites.

Small trees, small lianas, herbs and shrubs all contributed importantly to overall seedling densities, but there were pronounced differences between these growth forms with respect to the forest type (Figure 2.2, Table 2.8). Densities of small tree seedlings were highest in the primary forest site and lowest in the forest sites 1 and 5 years ago with the forest site logged 10 years ago being more or less intermediate. When compared to small liana seedlings, the forest site 1 year ago had value twice that of the primary forest site (Figure 2.2). Densities of both herb and shrub seedlings were almost three times higher in the logged forest sites compared to the primary forest site (Figure 2.2, Table 2.5).

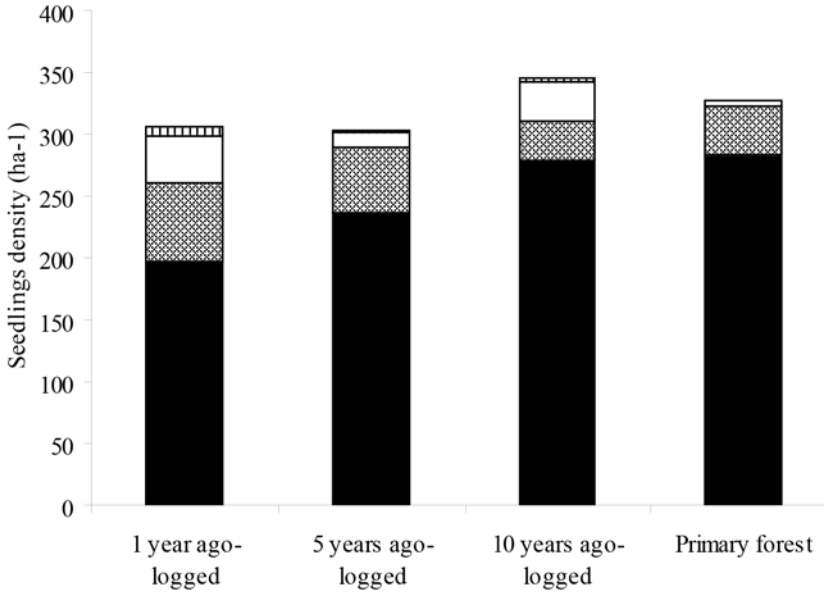

Figure 2.2
Density of seedlings of small trees (solid bars), small lianas (cross-hatched bars), herbs (open bars) and shrubs (horizontal bars) in four forest sites of the primary forest site and three selectively logged forest: logged 1 year ago, logged 5 years ago and logged 10 years ago.

Abundance and composition of different types of trees

Dicot trees were significantly less abundant in the forest sites logged 1 and 5 years ago than in the primary forest site, but dicot tree densities in the forest site logged 10 years ago were similar to those of the primary forest site (Tables 2.2 and 2.3). In the primary forest site, the dominant families were Dipterocarpaceae, Euphorbiaceae, Caesalpiniaceae, Burseraceae and Sapotaceae (Table 2.6). Species that contributed greatly to the dominance of these families were *Hopea semicuneata* and *Dipterocarpus lowii* (both Dipterocarpaceae), *Chaetocarpus castanocarpus* (Euphorbiaceae), *Cynometra elmeri* (Caesalpiniaceae) and *Palaquium stenophyllum* (Sapotaceae).

The abundance of tree species of *Hopea* was highest in the primary forest site (Table 2.6), only Dipterocarpaceae were more dominant in the forest site logged 10 years ago than in the primary forest site, while other dominant families of the three selectively logged forest sites were much less abundant compared with the primary forest site (Figure 2.3). *Hopea cernua* and *Hopea pachycarpa* were especially abundant in the three selectively logged forest sites (Table 2.9). Other

species that were abundant in the logged forest sites were *Syzygium tawahense* (Myrtaceae), *Shorea parvifolia* (Dipterocarpaceae), *Gironniera nervosa* (Ulmaceae), *Palaquium calophyllum* (Sapotaceae) and *Neoscortechinia kingii* (Euphorbiaceae).

Species that were only abundant in the forest site 10 years ago were *Allanthospermum borneensis* (Simaroubaceae), *Canarium denticulatum* (Burseraceae), *Chaetocarpus castanocarpus* and *Macaranga gigantea* (both Euphorbiaceae), *Gluta renghas* (Anacardiaceae), *Madhuca malaccensis* (Sapotaceae), *Myristica villosa* (Myristicaceae), *Scaphium macropodum* (Sterculiaceae), *Shorea parvifolia, Shorea inappendiculata* and *Vatica nitens* (all Dipterocarpaceae). All these species were absent or rare in the forest sites logged 1 and 5 years ago.

No significant differences between forest sites were observed in other types of palm trees. Palm trees were only abundant in the forest sites logged 1 and 10 years ago. Most stems were *Oncosperma horridum* (Table 2.9). Even though this species has a multi-stemmed growth form, total stem densities of this species were rather low, particularly in the forest site logged 10 years ago. Stem clusters of this species were present in only seven plots of the forest site logged 1 year ago and five plots of the one forest site logged 10 years ago.

Monocot trees were only represented by species of *Oncosperma horridum*. This species occurred in very low densities in the four forest sites and was never observed in the forest site logged 5 years ago or in the primary forest site. In contrast to this, there were 7 stems presence among the 150 plots of the forest site logged 1 year ago, making it the dominant monocot tree of this forest type (Table 2.3).

Abundance and composition of different types of saplings

Dicot saplings had a similar abundance in all four forest sites, with stem densities of around 240 stems ha^{-1} (Tables 2.2, 2.4). In the primary forest site, the dominant families were Euphorbiaceae, Dipterocarpaceae, Myristicaceae, Ebenaceae, Sapotaceae, and Polygalaceae (Table 2.7).

Table 2.6
The ten most abundant families, genera and species of trees in the primary forest site and three selectively logged forest: logged 1 year ago, logged 5 years ago and logged 10 years ago.

	Trees – Primary forest	Abun	%	Selectively logged forest								
				1 year ago	Abun	%	5 years ago	Abun	%	10 years ago	Abun	%
Families												
1	Dipterocarpaceae (6, 22)	123	73.7	Dipterocarpaceae (6, 20)	98	61.6	Dipterocarpaceae (6, 25)	92	63.2	Dipterocarpaceae (6, 30)	138	86.7
2	Euphorbiaceae (10, 13)	51	21.8	Myrtaceae (1, 6)	29	29.2	Sapotaceae (2, 6)	69	37.3	Sapotaceae (3, 5)	72	29.2
3	Caesalpiniaceae (5, 5)	34	17.7	Lauraceae (6, 7)	41	28.7	Myrtaceae (1, 4)	45	28.8	Euphorbiaceae (7, 9)	49	25.0
4	Burseraceae (2, 5)	33	16.2	Euphorbiaceae 10, 15)	45	23.1	Euphorbiaceae (8, 13)	50	25.0	Simaroubaceae (2, 2)	48	23.2
5	Sapotaceae (2, 6)	32	15.2	Myristicaceae (4, 5)	43	21.0	Burseraceae (3, 6)	22	13.0	Myrtaceae (1, 4)	28	13.9
6	Verbenaceae (1, 2)	39	14.7	Ebenaceae (1, 5)	24	13.5	Lauraceae (3, 3)	21	12.1	Burseraceae (3, 4)	23	13.2
7	Flacourtiaceae (1, 1)	19	13.2	Caesalpiniaceae (5, 7)	14	10.8	Myristicaceae (4, 8)	25	11.8	Myristicaceae (4, 6)	23	12.0
8	Myrtaceae (2, 4)	23	12.3	Burseraceae (3, 6)	18	10.5	Sterculiaceae (3, 5)	11	10.7	Caesalpiniaceae (3, 3)	14	9.7
9	Ebenaceae (1, 5)	29	11.7	Sapotaceae (2, 7)	22	10.5	Caesalpiniaceae (3, 5)	14	10.4	Anacardiaceae (3, 3)	15	9.3
10	Guttiferae (3, 3)	19	8.6	Annonaceae (6, 8)	18	8.7	Anacardiaceae (3, 5)	13	8.3	Sterculiaceae (3, 4)	14	9.2
Genera												
1	Hopea (Dipt, 2)	78	44.5	Shorea (Dipt, 12)	70	45.3	Shorea (Dipt, 14)	38	33.6	Shorea (Dipt, 18)	78	51.4
2	Dipterocarpus (Dipt, 4)	15	14.9	Syzygium (Myrt, 6)	29	28.8	Syzygium (Myrt, 4)	45	28.4	Madhuca (Sapo, 2)	60	22.8
3	Teijsmanniodendron (Verb, 2)	39	14.4	Eusideroxylon (Laur, 1)	25	17.9	Madhuca (Sapo, 3)	56	26.2	Allanthospermum (Sima, 1)	47	21.8
4	Hydnocarpus (Flac, 1)	19	13.1	Diospyros (Eben, 5)	24	13.1	Hopea (Dipt, 2)	24	13.2	Dipterocarpus (Dipt, 7)	22	15.9
5	Shorea (Dipt, 12)	22	11.9	Palaquium (Sapo, 4)	19	8.7	Palaquium (Sapo, 3)	13	11.8	Syzygium (Myrt, 4)	28	13.5
6	Diospyros (Eben, 5)	29	11.4	Hopea (Dipt, 2)	11	8.0	Vatica (Dipt, 3)	19	10.3	Vatica (Dipt, 2)	19	9.5
7	Syzygium (Myrt, 3)	22	11.4	Myristica (Myri, 2)	14	7.8	Alseodaphne (Laur, 1)	14	8.4	Chaetocarpus (Euph, 1)	12	8.7
8	Canarium (Burs, 3)	20	10.3	Knema (Myri, 1)	16	7.6	Horsfieldia (Myri, 2)	15	7.2	Canarium (Burs, 2)	14	7.4
9	Chaetocarpus (Euph, 1)	19	9.6	Artocarpus (Mora, 2)	11	6.7	Barringtonia (Lecy, 2)	15	7.0	Gluta (Anac, 1)	11	7.1
10	Palaquium (Sapo, 2)	13	7.9	Gymnacranthera (Myri, 1)	12	6.4	Gluta (Anac, 3)	10	6.6	Scaphium (Ster, 1)	10	6.8

Table 2.6 (continued)

Species												
1	*Hopea semicuneata*	76	43.4	*Syzygium tawahense*	15	19.1	*Syzygium tawahense*	42	26.5	*Madhuca malaccensis*	58	21.6
2	*Hydnocarpus polypetala*	19	13.1	*Eusideroxylon zwageri*	25	17.7	*Madhuca malaccensis*	46	21.1	*Allanthospermum borneensis*	47	21.5
3	*Teijsmanniodendron coriaceum*	32	11.5	*Shorea parvifolia*	24	15.3	*Hopea cernua*	21	11.1	*Syzygium tawahense*	21	9.8
4	*Chaetocarpus castanocarpus*	19	9.6	*Shorea pinanga*	17	8.5	*Alseodaphne elmeri*	14	8.4	*Shorea parvifolia*	12	9.2
5	*Syzygium tawahense*	16	8.8	*Knema laurina*	16	7.5	*Palaquium stenophyllum*	7	6.6	*Shorea inappendiculata*	10	9.1
6	*Dipterocarpus lowii*	9	8.3	*Palaquium calophyllum*	16	7.2	*Horsfieldia polyspherula*	14	6.6	*Chaetocarpus castanocarpus*	12	8.6
7	*Cynometra elmeri*	16	7.7	*Syzygium caudatilimba*	8	6.4	*Neoscortechinia kingii*	11	6.4	*Vatica nitens*	13	7.1
8	*Palaquium stenophyllum*	12	7.2	*Gymnacranthera*	12	6.3	*Shorea pinanga*	6	6.3	*Gluta renghas*	11	7.0
9	*Diospyros curranii*	16	6.6	*farquhariana*			*Lithocarpus coopertus*	9	5.8	*Scaphium macropodum*	10	6.8
10	*Chionanthus sp.1*	15	5.9	*Hopea dryobalanoides*	9	6.1	*Drypetes kikir*	11	5.8	*Myristica villosa*	12	6.5
				Diospyros borneensis	11	6.1						

In columns after each taxon the corresponding abundance (Abun), expressed as the densities of stems exceeding (dbh ≥ 10 cm) in height 1.3 m, and the percentage of important value index of all stems of trees exceeding in 1.3 height (%). In parentheses after families the numbers of observed genera and species and after genera the corresponding family and the number of observed species.

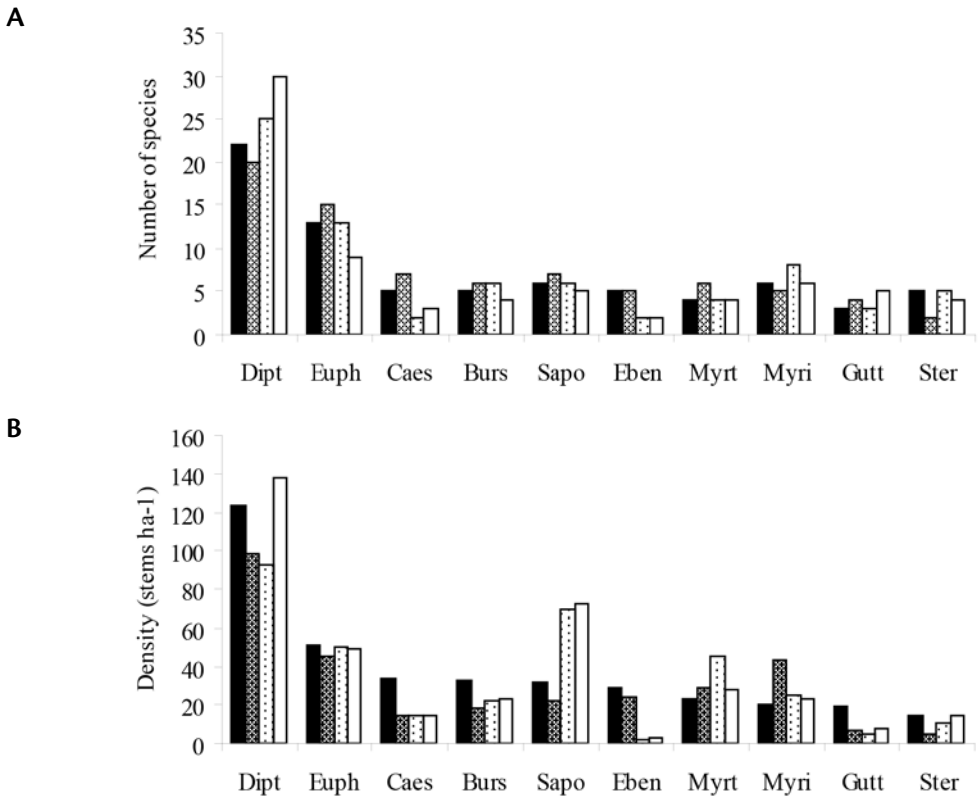

Figure 2.3
Stem density (A) and total observed species number (B) in four forest sites of the 10 most species-rich tree family of primary forest in Labanan, PT. Hutansanggam Labanan Lestari. Solid bars: primary forest site; cross-hatched bars: selectively logged forest; forest site logged 1 year ago; dotted bars: forest site logged 5 years ago; open bars: forest site logged 10 years ago.

Species that contributed greatly to the dominance of these families were *Hopea semicuneata* (Dipterocarpaceae), *Knema laurina* (Myristicaceae), *Croton argyratus, Koilodepas brevipes* and *Cleistanthus erycibifolius* (all Euphorbiaceae), *Xanthophyllum obscurum* (Polygalaceae), *Madhuca malaccensis* (Sapotaceae) and *Diospyros curanii* (Ebenaceae).

Generally the number of families of saplings in the 1 year ago logged site was about twice the number in the other sites (Table 2.7). However the differences between forest sites were less pronounced for the dominant dicot tree families (Table 2.6).

In the selectively logged forest sites, and particularly in the one logged 1 year ago, species of *Macaranga*, *Glochidion* and *Shorea* were more abundant than in the primary forest site. Apparently *Melastoma malabathricum* and *Glochidion arborescens* had ecological characteristics similar to species such as *Macaranga hypoleuca,* as it was fast-growing and particularly abundant in the selectively logged forest sites absent in the primary forest site (Table 2.7).

Dicot shrubs were the only life form more abundant in the forest site logged 5 years ago than in the other forest sites (Table 2.4). Dicot treelets were more abundance in the primary forest site than in the three logged ones. Typically, the dominant species were different in all four forest sites (Table 2.7). Some dicot liana species were abundant in the selectively logged forest sites, while being almost absent in the primary forest site. Species of *Uncaria* were only present in the forest sites 1 and 10 years ago (Table 2.9). Monocot herbs were less abundant than dicot herbs in the forest site logged 1 year ago and were absent in the three other forest sites (Table 2.4). Monocots were mainly represented by *Costus speciosus* (Table 2.9).

Abundance and composition of different types of seedlings

Dicot seedlings were more abundant in primary forest site than in the selectively logged forest sites, but total stem densities were highest in the forest site 10 years ago (Tables 2.2 and 2.5). In the primary forest site, the dominant families were Dipterocarpaceae, Euphorbiaceae, Annonaceae, Palmae and Ebenaceae (Table 2.8). The main representing these families were *Hopea semicuneata* and *Dipterocarpus acutangulus* (both Dipterocarpaceae), *Croton argyratus* and *Koilodepas brevipes* (both Euphorbiaceae), *Uvaria elmeri* (Annonaceae), *Daemonorops sabut* (Palmae) and *Diospyros macrophylla* (Ebenaceae).

There were significantly more small dicot liana seedlings in the forest sites logged 1 and 10 years ago, compared with the primary forest site (Table 2.5). Small dicot lianas were the only of species *Combretum nigricans* (Table 2.8) in the 2 × 2 m subplots. This species was very abundant in the forest site logged 1 year ago but was absent in the primary forest site. Seedlings of the species of *Strychnos axillaris* was present in the selectively logged forest sites, but were not observed in the primary forest site. Small dicot trees were more abundant in the primary forest site but not in the three logged ones (Table 2.5).

Dicot shrubs were more abundant in the forest site logged 1 year ago than in the other forest sites (Table 2.5). Dicot species were typically shrubs belonging to the genera of the Rubiaceae: *Ixora* and *Psychotria*. The first genus consists of

Table 2.7
The ten most abundant families, genera and species of saplings in the primary forest site and three selectively logged forest: logged 1 year ago, logged 5 years ago and logged 10 years ago.

	Saplings – Primary forest	Abun	%	Selectively logged forest								
				1 year ago	Abun	%	5 years ago	Abun	%	10 years ago	Abun	%
Families												
1	Euphorbiaceae (14, 16)	43	28.2	Euphorbiaceae (8, 13)	93	71.4	Dipterocarpaceae (5, 12)	38	42.7	Euphorbiaceae (7, 13)	35	40.8
2	Dipterocarpaceae (4, 9)	24	18.8	Dipterocarpaceae (2, 7)	24	23.7	Euphorbiaceae (9, 11)	43	41.2	Dipterocarpaceae (5, 13)	35	36.8
3	Myristicaceae (2, 3)	10	15.0	Myristicaceae (3, 4)	10	19.1	Sapotaceae (1, 3)	26	31.4	Melastomataceae (3, 5)	31	26.7
4	Ebenaceae (1, 4)	12	14.1	Myrtaceae (1, 4)	11	16.5	Burseraceae (2, 4)	13	18.7	Sapotaceae (2, 3)	15	22.7
5	Sapotaceae (2, 4)	11	14.0	Rubiaceae (5, 5)	17	15.3	Rubiaceae (4, 4)	15	17.7	Myrtaceae (1, 1)	11	19.0
6	Polygalaceae (1, 2)	9	13.5	Annonaceae (2, 4)	7	12.7	Lauraceae (4, 4)	12	15.1	Rubiaceae (7, 8)	18	16.3
7	Annonaceae (6, 6)	16	12.5	Ebenaceae (1, 3)	9	12.4	Myrtaceae (1, 2)	10	15.0	Ulmaceae (1, 1)	7	13.5
8	Myrtaceae (1, 4)	11	9.9	Tiliaceae (2, 2)	6	12.0	Annonaceae (4, 4)	9	10.9	Polygalaceae (1, 2)	8	13.1
9	Burseraceae (2, 3)	7	9.6	Sapotaceae (1, 2)	6	10.5	Polygalaceae (1, 3)	5	10.8	Anacardiaceae (3, 3)	10	10.7
10	Meliaceae (1, 3)	7	8.2	Papilionaceae (1, 1)	5	8.3	Fagaceae (2, 2)	4	10.6	Burseraceae (3, 5)	9	9.8
Genera												
1	Diospyros (Eben, 4)	12	15.3	Macaranga (Euph, 3)	37	24.9	Madhuca (Sapo, 3)	26	30.2	Shorea (Dipt, 7)	25	26.9
2	Xanthophyllum (Poly, 2)	9	13.7	Glochidion (Euph, 2)	32	23.0	Shorea (Dipt, 6)	21	23.4	Macaranga (Euph, 5)	12	19.4
3	Knema (Myri, 2)	8	11.7	Shorea (Dipt, 6)	23	20.8	Vatica (Dipt, 3)	12	17.0	Melastoma (Mela, 1)	27	19.2
4	Syzygium (Myrt, 4)	11	11.0	Syzygium (Myrt, 4)	11	15.4	Syzygium (Myrt, 2)	10	14.0	Syzygium (Myrt, 1)	11	18.0
5	Hopea (Dipt, 1)	10	10.2	Diospyros (Eben, 3)	9	11.4	Canarium (Burs, 2)	8	13.1	Madhuca (Sapo, 2)	12	18.0
6	Madhuca (Sapo, 2)	6	10.1	Knema (Myri, 2)	4	11.3	Koilodepas (Euph, 1)	15	12.4	Gironniera (Ulma, 1)	7	12.8
7	Croton (Euph, 2)	6	9.8	Koilodepas (Euph, 1)	10	10.1	Cleistanthus (Euph, 1)	10	11.9	Xanthophyllum (Poly, 2)	8	12.3
8	Cleistanthus (Euph, 2)	7	9.1	Palaquium (Sapo, 2)	6	9.7	Ixora (Rubi, 1)	11	10.2	Barringtonia (Lecy, 1)	3	9.3
9	Fordia (Papi, 1)	11	9.1	Baccaurea (Euph, 2)	4	9.2	Xanthophyllum (Poly, 3)	5	10.1	Fordia (Papi, 1)	7	7.6
10	Chionanthus (Olea, 2)	10	8.4	Polyalthia (Anno, 3)	5	8.9	Alseodaphne (Laur, 1)	6	8.3	Mallotus (Euph, 2)	6	7.6

Table 2.7 (continued)

Species												
1	*Hopea semicuneata*	10	10.2	*Glochidion arborescens*	25	16.8	*Madhuca malaccensis*	22	25.5	*Melastoma malabathricum*	27	19.1
2	*Fordia splendidissima*	11	9.0	*Macaranga hypoleuca*	24	16.0	*Syzygium tawahense*	9	12.4	*Syzygium tawahense*	11	17.8
3	*Knema laurina*	7	8.6	*Macaranga gigantea*	12	10.4	*Koilodepas brevipes*	15	12.2	*Madhuca malaccensis*	11	16.5
4	*Croton argyratus*	5	7.9	*Koilodepas brevipes*	10	10.0	*Cleistanthus erycibifolius*	10	11.7	*Gironniera nervosa*	7	12.6
5	*Xylopia ferruginea*	5	7.8	*Syzygium tawahense*	7	9.9	*Canarium denticulatum*	6	10.8	*Barringtonia macrostachya*	3	9.2
6	*Xanthophyllum obscurum*	3	7.1	*Knema laurina*	3	9.3	*Ixora fucosa*	11	10.1	*Xanthophyllum obscurum*	5	9.1
7	*Chionanthus sp.1*	8	7.0	*Fordia splendidissima*	5	7.5	*Vatica nitens*	4	8.4	*Shorea macroptera*	10	8.0
8	*Koilodepas brevipes*	7	7.0	*Diospyros borneensis*	6	7.2	*Alseodaphne elmeri*	6	8.2	*Fordia splendidissima*	7	7.5
9	*Xanthophyllum affine*	6	6.5	*Baccaurea sumatrana*	2	6.8	*Vatica oblongifolia*	7	7.3	*Macaranga hypoleuca*	5	7.3
10	*Cleistanthus erycibifolius*	4	6.4	*Chionanthus sp.1*	6	6.3	*Fordia splendidissima*	6	6.9	*Macaranga gigantea*	3	6.6

In columns after each taxon the corresponding abundance (Abun), expressed as the densities of stems exceeding dbh < 10 cm in height ≥ 1.5 m, and the percentage of important value index of all stems of saplings exceeding in dbh < 10 cm in height ≥ 1.5 m (%). In parentheses after families the numbers of observed genera and species and after genera the corresponding family and the number of observed species.

Table 2.8

The ten most abundant families, genera and species of seedlings in the primary forest site and three selectively logged forest: logged 1 year ago, logged 5 years ago and logged 10 years ago.

	Seedlings – Primary forest	Abun	%	Selectively logged forest								
				1 year ago	Abun	%	5 years ago	Abun	%	10 years ago	Abun	%
Families												
1	Dipterocarpaceae (4, 7)	92	37.7	Euphorbiaceae (8, 9)	42	21.9	Dipterocarpaceae (5, 11)	50	23.5	Dipterocarpaceae (5, 19)	65	30.2
2	Euphorbiaceae (7, 9)	47	24.7	Dipterocarpaceae (3, 5)	34	17.0	Euphorbiaceae (10, 11)	40	23.4	Melastomataceae (3, 3)	39	14.5
3	Annonaceae (4, 4)	20	11.3	Rubiaceae (8, 9)	22	15.3	Sapotaceae (2, 3)	29	15.8	Euphorbiaceae (11, 11)	17	12.2
4	Palmae (4, 4)	14	9.5	Melastomataceae (5, 5)	24	12.3	Papilionaceae (1, 1)	22	14.3	Papilionaceae (1, 1)	17	11.4
5	Ebenaceae (1, 4)	18	9.2	Lauraceae (6, 6)	12	9.1	Myrtaceae (1, 2)	22	13.5	Dryopteridaceae (1, 1)	25	9.7
6	Melastomataceae (2, 5)	11	8.5	Dryopteridaceae (1, 1)	13	8.7	Guttiferae (2, 2)	12	9.4	Sapotaceae (1, 1)	15	8.4
7	Oleaceae (1, 2)	11	7.8	Sapotaceae (3, 3)	16	8.2	Connaraceae (3, 3)	9	6.9	Guttiferae (3, 3)	11	8.1
8	Polygalaceae (1, 3)	8	6.1	Selaginellaceae (1, 1)	12	7.6	Melastomataceae (5, 6)	9	6.9	Rubiaceae (3, 3)	8	8.0
9	Rubiaceae (4, 4)	7	5.8	Myristicaceae (3, 3)	10	6.2	Burseraceae (2, 3)	8	6.5	Oleaceae (1, 1)	15	7.6
10	Symplocaceae (1, 1)	7	5.8	Anacardiaceae (5, 5)	7	6.0	Schizaeaceae (1, 1)	13	5.9	Anacardiaceae (3, 3)	12	6.7
Genera												
1	Hopea (Dipt, 1)	68	24.6	Shorea (Dipt, 3)	32	15.1	Fordia (Papi, 1)	22	13.3	Shorea (Dipt, 10)	38	19.3
2	Croton (Euph, 2)	22	11.9	Macaranga (Euph, 2)	20	9.8	Syzygium (Myrt, 2)	22	12.6	Melastoma (Mela, 1)	35	11.5
3	Diospyros (Eben, 4)	18	8.7	Nephrolepis (Dryo, 1)	13	8.2	Madhuca (Sapo, 2)	25	12.3	Fordia (Papi, 1)	17	10.4
4	Koilodepas (Euph, 1)	12	7.6	Selaginella (Sela, 1)	12	7.2	Koilodepas (Euph, 1)	17	10.3	Nephrolepis (Dryo, 1)	25	9.3
5	Chionanthus (Olea, 2)	11	7.2	Koilodepas (Euph, 1)	11	6.2	Calophyllum (Gutt, 1)	11	8.3	Madhuca (Sapo, 1)	15	7.8
6	Daemonorops (Palm, 1)	8	5.7	Combretum (Comb, 1)	11	4.9	Shorea (Dipt, 5)	13	7.0	Chionanthus (Olea, 1)	15	7.1
7	Pternandra (Mela, 3)	8	5.7	Diospyros (Eben, 2)	5	4.3	Vatica (Dipt, 2)	14	6.6	Dipterocarpus (Dipt, 4)	10	7.0
8	Xanthophyllum (Poly, 3)	8	5.7	Lygodium (Schi, 1)	9	4.3	Hopea (Dipt, 1)	16	6.0	Lygodium (Schi, 2)	15	5.7
9	Symplocos (Symp, 1)	7	5.4	Pternandra (Mela, 1)	8	3.9	Lygodium (Schi, 1)	13	5.6	Hopea (Dipt, 1)	9	5.4
10	Shorea (Dipt, 2)	11	5.3	Pleiocarpidia (Rubi, 1)	5	3.6	Dacryodes (Burs, 2)	7	5.0	Syzygium (Myrt, 2)	9	5.4

Table 2.8 (continued)

Species												
1	*Hopea semicuneata*	68	24.6	*Shorea parvifolia*	17	9.4	*Fordia splendidissima*	22	13.1	*Melastoma malabathricum*	35	11.4
2	*Croton argyratus*	21	11.6	*Macaranga hypoleuca*	17	8.8	*Madhuca malaccensis*	24	11.8	*Fordia splendidissima*	17	10.2
3	*Koilodepas brevipes*	12	7.5	*Nephrolepis bisserata*	13	8.1	*Syzygium tawahense*	20	11.8	*Nephrolepis bisserata*	25	9.2
4	*Chionanthus sp.1*	9	6.0	*Selaginella caulescens*	12	7.1	*Koilodepas brevipes*	17	10.2	*Madhuca malaccensis*	15	7.6
5	*Daemonorops sabut*	8	5.7	*Koilodepas brevipes*	11	6.2	*Calophyllum gracilipes*	11	8.2	*Chionanthus sp.1*	15	7.0
6	*Diospyros macrophylla*	14	5.6	*Combretum nigricans*	11	4.9	*Vatica nitens*	13	6.2	*Shorea macroptera*	12	5.4
7	*Symplocos crassipes*	7	5.4	*Shorea leprosula*	12	4.6	*Hopea cernua*	16	5.9	*Hopea cernua*	9	5.2
8	*Uvaria elmeri*	7	4.1	*Lygodium circinatum*	9	4.2	*Lygodium circinatum*	13	5.6	*Lygodium circinatum*	13	5.1
9	*Anaxagorea javanica*	4	3.8	*Pternandra rostrata*	8	3.9	*Gluta renghas*	7	4.9	*Syzygium tawahense*	7	4.7
10	*Dipterocarpus acutangulus*	8	3.7	*Bauhinia diptera*	7	3.6	*Alpinia galanga*	9	4.3	*Calophyllum gracilipes*	6	4.4

In columns after each taxon the corresponding abundance (Abun), expressed as the densities of stems exceeding per subplot 2 × 2 m, and the percentage of important value index of all stems of seedlings exceeding in subplot 2 × 2 m (%). In parentheses after families the numbers of observed genera and species and after genera the corresponding family and the number of observed species.

Table 2.9
Comparison between the number of trees (dbh ≥ 10 cm) per 1.5 ha, saplings (dbh < 10 cm) per 0.375 ha and several seedlings per 0.06 ha in ground cover recorded in subplot.

Family	Genus	Species	Life form	N0	N1	N2	N3	S0	S1	S2	S3
Trees (1.5 ha)											
▪ Dipterocarpaceae	Hopea	*cernua*	dicot tree	0	0	21	10	0	0	15	9
▪ Dipterocarpaceae	Hopea	*pachycarpa*	dicot tree	2	2	3	0	2	2	3	0
▪ Palmae	Oncosperma	*horidum*	palm tree	0	7	0	3	0	5	0	1
Saplings (0.375 ha)											
▪ Euphorbiaceae	Macaranga	*hypoleuca*	dicot tree	0	24	3	5	0	4	3	1
▪ Rubiaceae	Uncaria	*borneensis*	dicot liana	0	0	0	2	0	0	0	1
▪ Rubiaceae	Uncaria	*calophylla*	dicot liana	0	0	0	3	0	0	0	1
▪ Rubiaceae	Uncaria	*cordata*	dicot liana	0	6	0	0	0	1	0	0
▪ Zingiberaceae	Costus	*speciosus*	monocot herb	0	2	0	0	0	1	0	0
Seedlings (0.06 ha)											
▪ Cyperaceae	Mapania	*latifolia*	monocot grass	1	5	0	0	1	2	0	0
▪ Cyperaceae	Scleria	*terrestris*	monocot grass	2	3	0	0	1	2	0	0
▪ Dipterocarpaceae	Hopea	*semicuneata*	dicot tree	68	0	0	0	6	0	0	0
▪ Ebenaceae	Diospyros	*macrophylla*	dicot tree	14	0	0	0	2	0	0	0
▪ Euphorbiaceae	Macaranga	*hypoleuca*	dicot tree	0	17	1	1	0	5	1	1
▪ Ophioglossaceae	Helminthostachys	*zeylanica*	fern tree	0	3	0	0	0	3	0	0
▪ Selaginellaceae	Selaginella	*caulescens*	fern herb	0	12	0	0	0	5	0	0

After each family, genus and species name respectively life form, observed number of stems (N) and number of subplots having at least on stem exceeding of this species (S) per forest disturbance type (0 = primary forest site, 1 = forest site logged 1 year ago, 2 = forest site logged 5 years ago, 3 = forest site logged 10 years ago).

species that were mainly restricted to the primary forest site, while *Psychotria* sp.1 was most abundant in the forest site logged 1 year ago.

Monocot herbs were abundant in the forest site logged 5 years ago (Table 2.5) and this was mainly due to extensive ground cover of *Alpinia galanga* (Table 2.8), which was absent or rare in the other three forests.

Grass-like monocots were more abundant in the forest site logged 1 year ago (Table 2.5), mainly due to plentiful ground cover of *Mapania latifolia* and *Scleria terrestris* (Table 2.9). Both species were absent in two other logged forest sites.

Both palm lianas (rattans) and small palm trees were more abundant in the primary forest site than in the three selectively logged forest sites (Table 2.5). The climbing palm *Daemonorops sabut,* was the only climber that was very abundant in the primary forest site (Table 2.8). Other species were rare in all four forest sites.

Small liana ferns were more abundant in the forest site logged 5 year ago than in the other forest sites (Table 2.5). Two genus *Lygodium* and *Stenochlaena,* were abundant in the forest site logged 5 years ago, while in the other three forest sites these genera were absent or rare. These genera often form a very tangled mat at places where the small pioneer trees and small lianas are absent or rare.

Both herbaceous and small tree ferns were abundant in selectively logged forest sites, but were absent in the primary forest site (Table 2.5). Small tree ferns were represented solely by *Helmintostachys zeylanica,* a species that was only observed in the forest site logged 1 year ago. Of the same life form, the species *Selaginella caulescens* was also very abundant in the forest site logged 1 year ago, but absent in the three other forest sites (Table 2.9).

Discussion

Changes in forest structure and composition after logging compared to primary forest

Biodiversity levels indicate the stability of a forest community: the higher the levels of biodiversity, the more stable the community (Richards, 1964; Whitmore, 1990). In our study we compared forest sites which were logged 1, 5 and 10 years ago and a primary forest site. Our study covered canopy and forest floor vegetation, trees, saplings and seedlings, climbing trees (liana and rattan), non-rattan palms, herbs, epiphytes, and mosses.

Since we included 10 years ago logged forests, a before-, between- and after treatment study was not possible. We also did not include a heavily logged forest site, because these were not available within the forest concession. The distance of 50 m between the five transects per site is limited (risk of pseudo replication), but this distance has been used in other studies and is proposed as a standard by several authors (Slik *et al.*, 2002). The present comparison of the four forest sites: three forest sites logged selectively 1, 5 and 10 years ago (certified logging) and a primary forest site provides important information on the status of logged lowland rain forest in East Kalimantan. The logging procedures of our study sites are described in detail (Meijaard *et al.*, 2005). The present study showed that overall tree densities were significantly higher in the forest site of primary forest than in the sites 1 and 5 years ago, but approximately similar to that in the forest site logged 10 years ago (Table 2.3). The number of tall trees (dbh ≥ 10 cm) is very similar in the three logged forest sites of Labanan (492–558 stems ha^{-1}), suggesting that the impact of selective logging was similar for the three sites (Table 2.2). Nevertheless, we found small though significant differences in stem densities in the forest sites logged 1 and 5 years ago compared with the primary forest site (Table 2.3). In addition, typical sapling and seedling life forms, such as the fast growing species *Macaranga hypoleuca* were very abundant in the forest site logged 1 year ago less abundant in the forest sites 5 and 10 years ago, and absent in the primary forest site (Table 2.9). *Macaranga hypoleuca* is a very common and characteristic pioneer tree species in most of Southeast Asia and especially in East Kalimantan (Primack & Lee, 1991; Davies *et al.*, 1998; Slik *et al.*, 2000, 2002; Eichhorn *et al.*, 2006). Without information on species composition and diversity, a comparison of the vegetation structure in the four forests sites therefore suggested that selective low impact logging largely compensated for the strong negative impact of initial logging. However, we found that only a small number of pioneer tree species accounted for the high small tree densities in the forest site 10 years ago (Table 2.5). Our result therefore show that abundance of tree species regeneration, as was observed at several sites in East Kalimantan (e.g. Siegert *et al.*, 2001; Slik *et al.*, 2002; Yassir *et al.*, 2010), does not in itself, ensure recovery of the forest's original botanic diversity. Information on species composition is needed to know how many species of trees and other plants are able to recover in the selectively logged forest sites (Tables 2.3, 2.4 and 2.5).

The total number of saplings species belonged to one or a few different species in the selectively logged forest sites (Tables 2.4); this means that new trees of sapling which entered the overstorey (dbh ≥ 10 cm), whereas the in-growth of seedlings in the selectively logged forests consisted of many species (Table 2.5); this was apparently due to more light on the open places to grow the pioneer species (Arbainsyah, pers. obs.). This finding doesn't contradict the generally held view

that pioneer species occur only after disturbance when the light or temperature levels are raised substantially (Bazzaz & Pickett, 1980; Uhl & Clark, 1983; Swain & Whitmore, 1988; Vazques-Yanes & Orozco-Segovia, 1993; Eichhorn *et al.*, 2006). After selective logging of the forest, many small pioneer tree seedlings were therefore likely to be available for tree establishment and this would explain why in a forest site, which was logged previously, seedlings could become dominant. This explanation implies that after selectively logging, there will not be a permanent deforestation at Labanan, as ingrowth of seedlings of small trees in the topsoil were most abundant in the forest site logged 10 years previously (Figure 2.2).

10 years after selective logging, the sapling and tree densities were still high in the forest sites, but rather low in the forest sites logged 1 and 5 years ago, compared with the primary forest site. Apart from the differences in tree densities, there was also a difference in tree composition among the selectively logged forest sites (1, 5 and 10 years ago). The most abundant tree species in the forest site logged 10 years ago were *Madhuca malaccensis*, *Allanthospermum borneensis* and *Syzygium tawahense* (Table 2.6). *Syzygium tawahense* also belongs to the highest 10 most abundant tree species of forest sites logged 1 and 5 years ago (Table 2.6, Figure 2.4).

The impact of selective logging on plant diversity

Comparison of the plant diversity in different habitats shows that the overall impact of logging on plant species richness is highly dependent on the scale of assessment. We realize that the maximum number of 156 tree species we found in our study does represent of the tree species diversity in Borneo (Raes, 2009). Since most species in hyperdiverse rainforests occur in low densities, their response to logging can not be assessed with small sampling plots only. So we suggest that our study at best, gives an indication of an impact of logging on the more common tree species. We also realize that the tree category > 10 cm dbh will include a wide range of diameter classes, which may have changed following logging. Therefore we recommend including more diverse diameter categories in a follow-up study (Tables 2.3, 2.4 and 2.5). Logging in a sense is equivalent to gap formation in the forest canopy, but at a much larger scale and will surely alter the nature of the original forest (Kartarwinata, 1977; Eichhorn *et al.*, 2006). Similar scale-dependent effects of disturbance on species diversity have also been reported by other studies, for example on the abundance of bark beetles in pine forests of Finland (Poltonen et al. 1998). In tropical rain forests, the impact of logging on species richness and evenness in butterflies has been shown to be highly scale-dependent as well (Hamer & Hill, 2000; Cleary, 2002; Summerville & Crist, 2002). As a result, numbers of trees and small dicot trees were always higher in the primary forest site (Tables 2.3, 2.6), this was mainly due to the

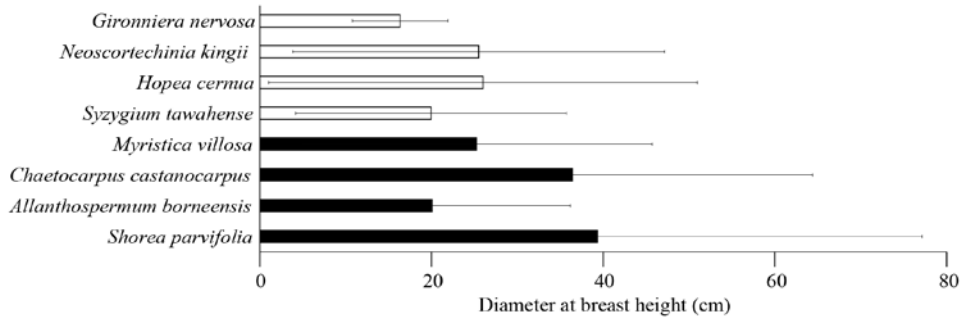

Figure 2.4
Diameter at breast height (average + standard deviation) of four species abundant in three logged forest sites (open bars) and of four species abundant only in forest site logged 10 years ago (solid bars).

abundant regeneration of invasive species such as *Hopea semicuneata* (Tables 2.7, 2.8), this species is not logged and the mother tree was absent in the three logged forest sites (Table 2.9). For forest regeneration it is important that the high richness of saplings were found in the forest site logged 1 year ago (Table 2.4). When taxonomic composition was compared species diversity was higher in the in the forest site logged 1 year ago than in the primary forest site (Table 2.3). Our study showed that the abundance of Caesalpiniaceae was considerably decreased in the selectively logged forest sites relative to the primary forest site, whereas the abundance of Dipterocarpaceae, Sapotaceae and Euphorbiaceae increased in the selectively logged forest sites (Figure 2.3). The latter family is typical fast-growing pioneer taxa throughout the tropics (Turner, 2001) and are of little economic interest. Our results show that, despite attaining a height comparable to that of the primary forest site, selectively logged forest sites have different plant taxa (Tables 2.3, 2.4 and 2.5).

Total numbers of trees accounted for a higher overall plant diversity in primary forest sites, while the number of tree species was higher in the forest site logged 1 year ago (Table 2.3). Saplings had a more or less similar diversity in all forest sites, while the number of sapling species was higher in the primary forest site (Table 2.4). While numbers of in-growth of seedlings was higher in the forest site logged 10 years ago, the number of seedling species was higher in the forest site logged 1 year ago (Table 2.5).

Conclusions

Overall, our study has revealed a rich natural vegetation on Borneo and major differences in the vegetation structure, composition and in plant diversity be-

tween selectively logged forest sites and a primary forest site. We have confirmed the importance of distinguishing between primary forests as opposed to selectively logged forests for documenting and interpreting plant species richness for sustainable forest exploitation in tropical rain forest. Selectively logged rain forest of this study still showed a high regenerating diversity of plants.

Logging practices in selectively logged forest with normal management operations have not resulted in a high deforestation of the study sites. The tree numbers still recovered with abundant regeneration. The numbers of tree species composition were clearly affected and neither increased nor decreased within forest sites logged 5–10 years ago.

Composition of saplings species were fewer within in selectively logged forest sites, in the 5–10 years ago-logged sites than in primary forest site. This indicates that the selectively logged forests have more or less the same value in evenness number species. These saplings will therefore slowly form a lower and lower proportion of all saplings present in selectively logged forest sites. That means that the impact of logging results in the same proportion of the total number of saplings in all selectively logged forest sites in near future.

The ingrowth of seedlings of the *Macaranga hypoleuca* was found to be independent of the light availability in the forest understorey. Instead the number of this species depended strongly on the presence of mature parent trees species in and around the forest sites. This caused one species (*Macaranga hypoleuca*) to be the most dominant species in the 1 year ago logged forest site. In the 5 and 10 year ago forest sites Macaranga hypoleuca seedlings were probably replaced by competition with seedlings from other species. However, apart from seedling numbers, did depend strongly on the light availability in the forest understorey.

The diversity index used as indicators the stability regeneration for all growth stage of forest community showed that were still floristically very diverse and indicated that the selectively logged forest sites affected the abundance of species rather than species richness itself. This renders the selectively logged forest still valuable for conservation, especially since the studied forests were in selectively logged forest sites and tree species diversity to be higher in diversity of plant.

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3

Plant communities in FSC-candidate, selectively logged forests compared to primary forest in relation to stem diameter and plant functional types

Journal of Forestry Research (submitted)

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Abstract

The aim of our study is to analyze the impact of selective logging and forest recovery on patterns in forest structure, tree species composition, and tree species diversity in relation to stem diameter and Plant Functional Type (PFT). Our study compared FSC-candidate forest sites which had been logged selectively 1, 5 and 10 years ago to primary lowland dipterocarp rainforest in the Berau region of East Kalimantan. Logged forest sites under different logging regimes showed significant differences in forest structure compared with the primary forest site. In the diameter class, some logged forest sites showed a significant reduction in the frequency of diameter classes compared to the primary forest site. The diameter classes were significantly smaller and the number of tree species was significantly lower in the selectively logged forest sites compared to the primary forest site. Species specific wood density was used to assign species to three classes of PFT (light, medium, heavy wood). Logging increased the number of light hardwood stems in small diameter classes. In the larger diameter classes (> 60 cm dbh) a strong increase of light hardwood numbers were found in the selectively logged forest sites. Our results indicate that both diameter classes and plant functional types are affected by selective logging and recovery after logging in tropical lowland forest.

Key words: Forest recovery; Growth form; Kalimantan; Species richness; Tropical rain forest.

Introduction

Most of the tropical rainforest lowland areas in East Kalimantan were covered with primary dipterocarp forest until the early 1970s (Slik *et al.*, 2002). At present however, most of these lowland dipterocarp forests have been selectively logged, burnt, or converted into agricultural land (oil palm), with only a few small undisturbed areas remaining (Slik *et al.*, 2002; Slik & Eichhorn, 2003; Eichhorn *et al.*, 2006; Arbainsyah *et al.*, 2014). Recovery of the vegetation to pre-logging conditions will be slow since logging in tropical forest has a significant effect on the forest understorey (Webb, 1998; Woods, 1998; Pinard *et al.*, 2000; Slik *et al.*, 2002). Two certification systems for sustainable forest management have been introduced in Indonesia: the international Forest Stewardship Council (FSC) and the national Lembaga Ekolabel Indonesia (LEI). The Lembaga Ekolabel Indonesian selective logging system allows a selective logging intensity of ≤ 8 trees/ha and tree cutoffs in the diameter > 60 cm associated with a felling cycle of 40–60 years depending on site conditions (Sist et al. 2003; van Kuijk et al. 2009). Although FSC is an internationally recognized certification system claiming to guarantee sustainable timber offtake from tropical rainforests (ITTO, 2004), the impact of FSC-certified logging on biodiversity has rarely been quantified (Van Kuijk *et al.*, 2009).

Studies in which the impact of tropical deforestation by commercial logging on tree diversity and forest structure has been addressed (Slik *et al.*, 2002; Verburg & Van Eijk-Bos, 2003; Arbainsyah *et al.*, 2014) provided limited information on the impact of certified selective logging and forest recovery. Through the present research we will specifically target the lack of knowledge about suitable biological indicators for sustainable forest management at the forest management unit level (Ghazoul & Hellier, 2000; De Iongh & Persoon, 2010).

Important factors for forest recovery are: 1) seed bank, 2) topography and 3) light (Woods, 1998; Fredericksen & Mostacedo, 2000; Slik & Eichhorn, 2003; Arbainsyah *et al.*, 2014). The majority of plants in lowland forest of Kalimantan are non-pioneer species, which are lacking soil seed banks, while seed import from surrounding primary forest areas is likely to be low since these have been heavily impacted by logging activities (Garwood, 1989; Verburg & Van Eijk-Bos 2003; Eichhorn *et al.*, 2006). Increased light levels in the understorey of logged forests result in the rapid growth of many herbaceous and woody pioneer species. Since climax species usually have no seed bank (Swaine & Whitmore, 1988; Garwood, 1989; Vazquez-Yanes & Orozco-Segovia, 1993; Eichhorn *et al.*, 2006), the early recovery of these species in logged forests strongly depends on surviving saplings, sprouting trees and germination of seeds from the seed rain (Slik *et*

al., 2002; Slik & Eichhorn, 2003). This would have important consequences for tropical forest recovery after logging and should therefore be considered in the development of any sustainable forest management system.

The most important factor influencing forest recovery after logging is the increased light penetration to the forest floor. Canopy openness at ground level (1–2 m height) generally increases from 2–7% in old growth forest to 20–30% in selectively logged forest (Slik *et al.*, 2002). Increased light intensities combined with the reduced number of plants in the forest understorey favor the establishment of pioneers (Nieuwstadt *et al.*, 2001; Slik *et al.*, 2002; Slik & Eichhorn, 2003; Eichhorn *et al.*, 2006; Arbainsyah *et al.*, 2014). These pioneers will compete with surviving trees for available resources, especially light. Since pioneer species can have very high growth rates under high light conditions (e.g. after logging), regeneration of other tree species in the forest landscape might be seriously hampered (Uhl *et al.*, 1981; Slik *et al.*, 2002; Slik & Eichhorn, 2003; Arbainsyah *et al.*, 2014).

Both the tree species diversity and the forest structure, in terms of species per diameter class are considered to be important factors to take into account when measuring the impact of SFM (Ter Steege & Hammond, 1996, 2001; Verburg & Van Eijk-Bos, 2003; Meijaard *et al.*, 2005). Logging activities affect ecosystem processes in many different ways, but could be especially harmful to endemic populations of plants and animals (Verburg & Van Eijk-Bos, 2003; Sist *et al.*, 2003; Meijaard et al. 2005; Arbainsyah et al. 2014). In the process of succession after logging, pioneer trees reach successively larger diameter classes faster than most non-pioneer species (Slik *et al.*, 2002; Verburg & Van Eijk-Bos 2003). In addition, some light demanding, non-pioneer tree species may have higher growth rates after logging (Slik *et al.*, 2002; Slik & Eichhorn, 2003). Differential species response to disturbance after logging can result in differences in tree composition within tree diameter classes (Sheil, 1999; Okuda *et al.*, 2003; Verburg & Van Eijk-Bos, 2003). A classification derived from the pioneer versus climax species concept was published by Swaine and Whitmore (1988) and is often used to analyze the impact of pioneer species on forest recovery (e.g. Slik & Eichhorn, 2003). One study of primary forest succession used an analysis in which the data set was divided into different stem diameter classes to unravel changes in the tree community compared to primary forest succession in Uganda (Sheil, 1999). Recently, species-specific Plant Functional Types (PFT) have been used by several authors (Brown & Lugo 1990; Ter Steege & Hammond, 1996, 2001; Verburg & Van Eijk-Bos, 2003). With the PFT, a trade-off is assumed between growth rate of the PFT classes light, medium and heavy hardwood. Species that produce light hardwood can grow quickly and are able to emerge rapidly after gap for-

mation. At the other extreme, species that produce heavy hardwood have lower growth rates (Verburg & Van Eijk-Bos, 2003).

Here we present a detailed analysis of the tree communities, and the abundance of different PFTs in primary forest and forest selectively logged 1, 5 and 10 years ago in East Kalimantan. Patterns in species diversity and composition are related to diameter classes and Plant Functional Types and analysed for selectively logged forest sites and to compare these with primary forest.

Materials and methods

Study area

The study area is located in lowland forest within the Perseroan Terbatas-PT. Hutansanggam Labanan Lestari forest concession in Labanan, Berau district, in the northeastern part of the Indonesian province of East Kalimantan (Figure 3.1). The largest part of this concession area belongs to the state-owned logging company Perseroan Terbatas-PT. Inhutani I. The elevation range within the study area is 25 to 140 m above sea level. The topography within the study area in all sites consists of a relatively homogenous rolling hilly landscape with shallow valleys and gullies. The forest type can be described as a Dipterocarp hill forest which is relatively homogenous throughout all study sites. The soils consist of loamy clay and sandy soils with a top soil layer of approximately 5-10 cm (Mantel *et al.*, 2002).

Forest structure

Sites were selected in primary forest (1 site) and selectively logged forest (3 sites) (Figure 3.1). In each site, all trees were systematically recorded along a line transect of 10 × 300 m. In total, 20 line transects were sampled: 5 in primary forest and 5 in each of the 3 selectively logged forest areas. We divided each line transect into 30 plots of 10 × 10 m (a total of 150 plots in each site). The Basal Area (BA) removed by logging and total damage caused by logging on the number of stems was derived from field measurements of trees with a dbh ≥ 10 cm. Basal Area (BA) was calculated as BA = πx(0.01xdbh/2)2 (Jost 2006). Plants were sampled and later identified at the Wanariset Herbarium Samboja, i.e. in case of a fertile plant, and labeled (vouchers stored in the Herbarium Wanariset Samboja, Indonesia). Tree species diversity and tree density in the plots were compared across diameter classes and disturbance types (primary, logged selectively 1, 5 and 10 years ago) (Figure 3.1).

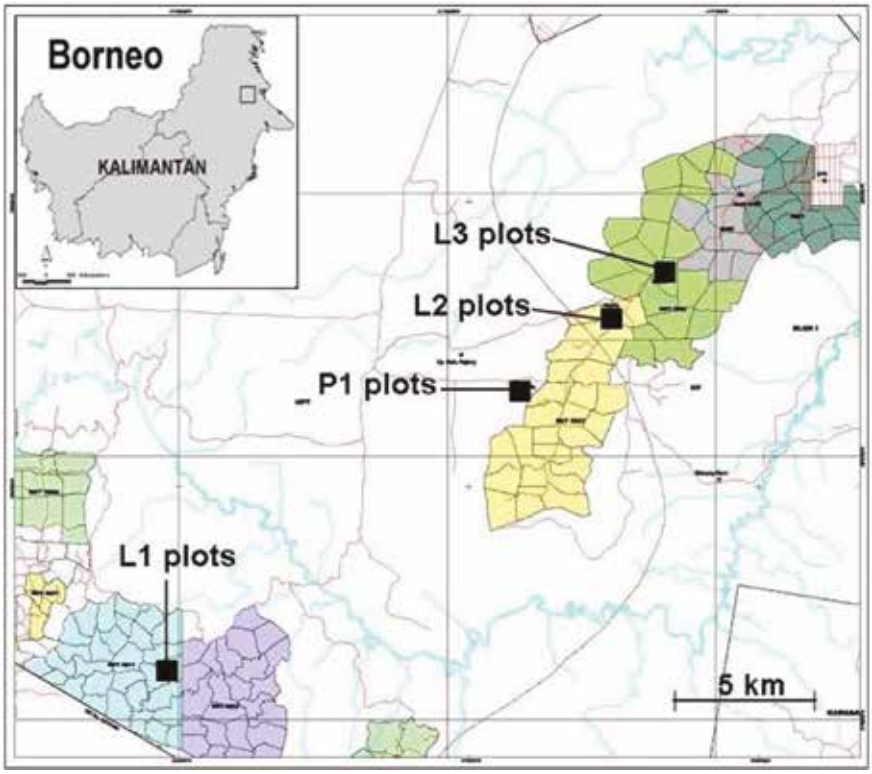

Figure 3.1
Map of East Kalimantan with the location of study sites: P1 plots: primary forest site, L1 plots: forest site logged 1 year ago (2011), L2 plots: forest site logged 5 years ago (2007), L3 plots: forest site logged 10 years ago (2003).

Tree species composition

Trees classified by Plant Functional Types (PFT) and the tree diameter composition of the forest were used to summarize compositional dynamics based on taxonomic literature (Burgess, 1966; Soerianegara & Lemmens, 1993; Lemmens *et al.*, 1995; Sosef *et al.*, 1998; Slik & Eichhorn 2003; Verburg & Van Eijk-Bos 2003) and information from herbarium labels of specimens stored in the Wanariset Herbarium Samboja. All tree stems were grouped into the following diameter (dbh) classes: 10–<20 cm (small trees), >20–30 cm (lower and middle canopy trees), >30–40 cm, >40–50 cm, >50–60 cm (middle and upper canopy trees), >60–70 cm, >70–80 cm, >80 cm (emergent trees). The number of tree species and number of individual trees in each diameter class in the primary forest site and the selectively logged forest (3 sites) is shown in Figure 3.1.

Plant functional types in tree densities

To study the growth rate relationship between PFT, in each site the average tree species diameter was calculated for all stems and species. For PFT classifications, wood descriptions for tree species were derived from Burgess (1966); Soerianegara and Lemmens (1993); Lemmens *et al.* (1995); Sosef *et al.* (1998) and Verburg and Van Eijk-Bos (2003). Relations between PFT and tree density were determined by summing the number of trees in the three PFT classes (light, medium and heavy hardwood) within each disturbance type (primary forest, forest logged selectively 1, 5 and 10 years ago).

Data analyses and statistics

Statistical analyses were performed using Microsoft Excel and SPSS 13.0 software. We calculated the mean and standard deviation for the tree densities per diameter class, and tree species number per diameter class by the three PFT classes (light, medium and heavy hardwood). Data were log transformed to normalize the distribution. Tree species diversity within plots was compared between the selectively logged forest and primary forest sites. These comparisons were made to compensate for differences in sample sites between selectively logged forest sites in comparison to a primary forest site. Differences between sites were tested using the Fisher's Least Significant test (one-way ANOVA, using log transformed data, with Bonferroni multiple comparison test).

Results

Forest structure after selective logging

Compared to the primary forest site, Basal Area (BA) was significantly lower in forest sites logged selectively 1 and 5 years ago , but not significantly different in the forest site logged 10 years ago (Table 3.1). Throughout the selectively logged forest sites, no significant differences were found in the number of tree stems removed, the total number of damaged tree stems, the BA of tree stems removed or total damage to the number of tree stems (Table 3.1).

We compared the abundance of stems per size class for forest selectively logged 1, 5 and 10 years ago. Throughout the sites, the number of stems in the smallest diameter class (10–20 cm dbh per 100 m^2) appeared to be higher than the number of stems in the other diameter classes (>20 cm dbh) (Table 3.2). The forest site logged selectively 1 year ago had a significantly lower number of stems in the

>20–30 cm dbh class than the primary forest site. The forest sites logged selectively 5 and 10 years ago had significantly lower numbers of stems in the 10–<20 cm dbh class than the primary forest site (Figure 3.2a; Table 3.2).

Table 3.1
Forest type (primary forest, selectively logged forest: 10, 5 and 1 year ago), average basal area (BA) before logging (BA = estimated for logged forest sites), number of stems, BA removed by logging and total damage to all stems ≥ 10 diameter caused by logging on the number of stems and BA. **Bold** averages for selectively logged forest sites differ significantly from those of the primary forest site (with Bonferroni correction for multiple tests).

Forest type	Present BA* (per 100 m²)	Removed (per 100 m²)		Total damage (per 100 m²)	
		Stems	BA	Stems	BA
Primary forest	0.31 ± 0.35	0	0	0	0
Logged, 10 year ago	0.23 ± 0.20	0.09 ± 0.29	0.04 ± 0.13	0.43 ± 0.73	0.06 ± 0.13
Logged, 5 years ago	**0.20 ± 0.19**	0.10 ± 0.32	0.04 ± 0.15	0.35 ± 0.58	0.07 ± 0.17
Logged, 1 years ago	**0.20 ± 0.28**	0.07 ± 0.26	0.03 ± 0.13	0.33 ± 0.56	0.06 ± 0.15

There were no significant differences in the number of stems in the 30–70 cm dbh class between the forest sites selectively logged and the primary forest site. However, the number of stems in the >70–80 cm dbh class was significantly lower in the forest sites logged selectively 1 and 5 years ago than in the primary forest site (Table 3.2). No significant differences were found in the number of stems in the > 80 cm dbh class across all forest sites (Table 3.2).

The number of tree species in the >20–30 cm dbh class per surface area was significantly lower in the forest selectively logged 1 year ago than in the primary forest site (Table 3.3). The number of tree species in the >30–70 cm dbh class did not differ significantly between any selectively logged site and the primary forest site. The number of tree species in the >70–80 cm dbh class was significantly lower in the forest sites selectively logged 1 and 5 years ago than in the primary forest site (Table 3.3). No significant differences were found in the number of tree species > 80 cm dbh throughout the forest sites (Table 3.3).

Tree species composition according to diameter class

The number of tree species in the 10–<20 cm dbh class in the selectively logged forest sites 5 and 10 years ago was significant lower than in the primary forest site (Table 3.3). However, the total number of tree species in the 10–<20 cm dbh class was higher in the forest site selectively logged 1 year ago than in all other forest sites (Figure 3.2b). In some selectively logged forest sites, the number of tree species

Table 3.2
Comparison between the abundance number of tree individuals per dbh class (average ± standard deviation) for all species combined and forest sites.

Forest type	Abundance stems (per 100 m²)							
	10 -< 20 cm	> 20 - 30 cm	> 30 - 40 cm	> 40 - 50 cm	> 50 - 60 cm	> 60 - 70 cm	> 70 - 80 cm	> 80 cm
Primary forest	2.34 ± 1.66	0.85 ± 0.86	0.37 ± 0.63	0.26 ± 0.50	0.09 ± 0.31	0.05 ± 0.23	0.08 ± 0.27	0.03 ± 0.20
Logged, 10 years ago	**1.85 ± 1.21**	0.97 ± 0.95	0.41 ± 0.59	0.24 ± 0.49	0.13 ± 0.37	0.08 ± 0.27	0.03 ± 0.18	0.01 ± 0.08
Logged, 5 years ago	**1.79 ± 1.46**	0.82 ± 1.00	0.27 ± 0.52	0.23 ± 0.47	0.14 ± 0.38	0.06 ± 0.24	**0.02 ± 0.14**	0.01 ± 0.08
Logged, 1 years ago	1.99 ± 1.58	**0.55 ± 0.75**	0.39 ± 0.67	0.20 ± 0.49	0.07 ± 0.26	0.04 ± 0.20	**0.01 ± 0.08**	0.03 ± 0.18

Abundance expressed as densities of stems exceeding 1.3 m in height. The number of species in dbh classes ≥ 10 cm on 1.5 ha (150 times 10x10 m) in the primary forest site and three selectively logged forest sites: logged 10, 5 and 1 year ago. **Bold** averages for selectively logged forest sites differ significantly from those of the primary forest site (with Bonferroni correction for multiple tests)

Table 3.3
Comparison between the abundance of tree species per dbh class (average ± standard deviation) for all trees combined and forest sites.

Forest type	Species (per 100 m²)							
	10 -< 20 cm	> 20 - 30 cm	> 30 - 40 cm	> 40 - 50 cm	> 50 - 60 cm	> 60 - 70 cm	> 70 - 80 cm	> 80 cm
Primary forest	2.18 ± 1.55	0.82 ± 0.82	0.35 ± 0.58	0.26 ± 0.50	0.09 ± 0.31	0.05 ± 0.23	0.08 ± 0.27	0.03 ± 0.20
Logged, 10 year ago	**1.74 ± 1.10**	0.95 ± 0.94	0.41 ± 0.59	0.24 ± 0.49	0.12 ± 0.35	0.08 ± 0.27	0.03 ± 0.18	0.04 ± 0.20
Logged, 5 years ago	**1.72 ± 1.40**	0.79 ± 0.96	0.27 ± 0.50	0.23 ± 0.47	0.14 ± 0.38	0.06 ± 0.24	**0.02 ± 0.14**	0.03 ± 0.16
Logged, 1 years ago	1.86 ± 1.47	**0.53 ± 0.72**	0.38 ± 0.66	0.19 ± 0.46	0.07 ± 0.26	0.04 ± 0.20	**0.01 ± 0.08**	0.01 ± 0.12

Abundance expressed as densities of stems exceeding 1.3 m in height. The number of species in dbh classes ≥ 10 cm on 1.5 ha (150 times 10x10 m) in the primary forest site and three selectively logged forest sites: logged 10, 5, and 1 year ago. **Bold** averages for selectively logged forest sites differ significantly from those of the primary forest site (with Bonferroni correction for multiple tests)

increased with increasing diameter classes up to the >60 cm dbh class, whereas for the >60 cm dbh classes, the number of species decreased with decreased diameter classes in selectively logged versus the primary forest site (Figure 3.2b).

Table 3.4 summarizes the relative abundance of tree species in the primary forest site and selectively logged forest sites in each PFT class. The classes of PFT in heavy hardwood and the total number of species were comparable in abundance in all four forest sites, with a total species abundance of around 22 species ha^{-1} (Table 3.5). In the primary forest site, the dominant PFT species in heavy hardwood were *Cynometra elmeri* (Caesalpiniaceae), *Hopea semicuneata* (Dipterocarpaceae) and *Teijsmanniodendron coriaceum* (Verbenaceae).

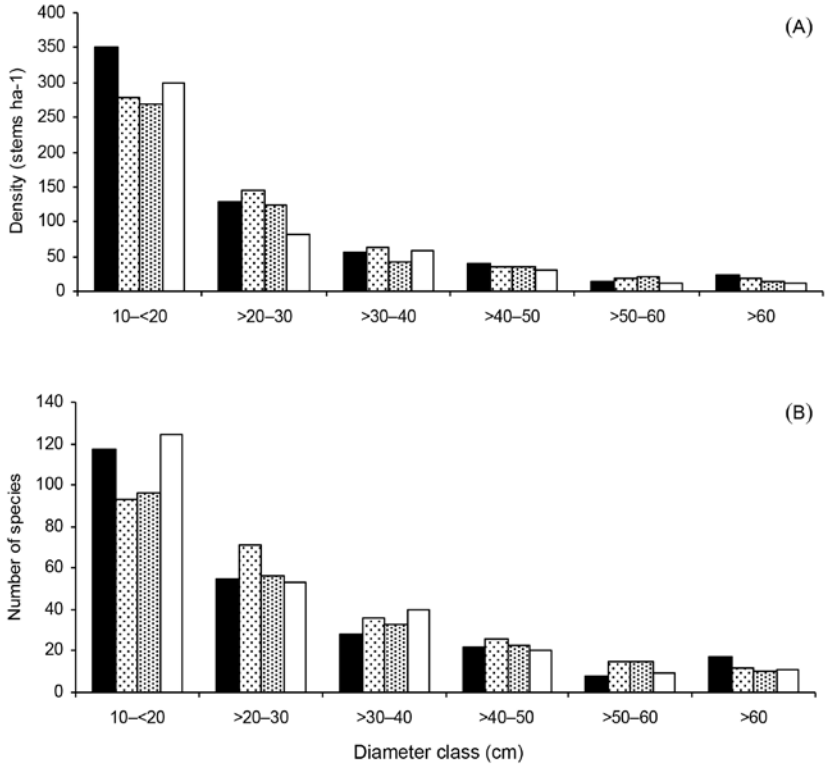

Figure 3.2
Stem density (A) and total observed species number (B) in four forest sites of the relative distribution among trees ≥ 10 cm dbh classes of primary forest in Labanan, PT. Hutansanggam Labanan Lestari. Solid bars: primary forest site; cross-hatched bars: selectively logged forest site logged 10 years ago; dotted bars: forest site logged 5 years ago; open bars: forest site logged 1 year ago.

The greatest abundance in total number of tree species was found for the medium hardwood PFT class, with 73 species in the forest site selectively logged 1 year ago and 72 in the primary forest site; the overall number of species for the medium hardwood PFT class was much lower in the other forest sites (Table 3.5). The light hardwood PFT class had a higher total number of tree species in the forest site logged 1 year ago than all other forest sites (Table 3.5). As expected, pioneer species, notably *Macaranga gigantea* (Euphorbiaceae), had a high abundance of tree species in the forest site selectively logged 10 years ago; none were observed in the other forest sites (Table 3.4).

Table 3.4
List of plant functional types of light, medium and heavy hardwood (Burgess 1966; Soerianegara & Lemmens 1993; Lemmens et al. 1995; Sosef et al. 1998) of tree species that are abundant in at least one of the forest sites.

Plant functional types	Species name	Primary forest	Selectively logged forest		
			10 yrs ago	5 yrs ago	1 yr ago
Light	*Alseodaphne elmeri* (Lauraceae)	–	–	+	–
	Barringtonia macrostachya (Lecythidaceae)	–	–	+	–
	Gymnacranthera farquhariana (Myristicaceae)	–	–	–	+
	Horsfieldia polyspherula (Myristicaceae)	–	–	+	–
	Knema laurina (Myristicaceae)	–	–	–	+
	Macaranga gigantea (Euphorbiaceae)	–	+	–	–
	Myristica villosa (Myristicaceae)	–	+	–	–
	Neoscortechinia kingii (Euphorbiaceae)	–	+	+	–
Medium	*Shorea parvifolia* (Dipterocarpaceae)	–	+	–	+
	Shorea pinanga (Dipterocarpaceae)	–	–	–	+
	Chaetocarpus castanocarpus (Euphorbiaceae)	+	+	–	–
	Chionanthus sp.1 (Oleaceae)	+	–	–	–
	Cratoxylum sumatranum (Hypericaceae)	+	–	–	–
	Diospyros borneensis (Ebenaceae)	–	–	–	+
	Diospyros curranii (Ebenaceae)	+	–	–	–
	Gironniera nervosa (Ulmaceae)	–	–	+	–
	Gluta renghas (Anacardiaceae)	–	+	–	–
	Hydnocarpus polypetala (Flacourtiaceae)	+	–	–	–
	Kayea borneensis (Guttiferae)	+	–	–	–
	Madhuca malaccensis (Sapotaceae)	–	+	+	–
	Palaquium calophyllum (Sapotaceae)	–	–	–	+

Table 3.4 (continued)

Heavy	*Palaquium stenophyllum* (Sapotaceae)	+	–	–	–
	Scaphium macropodum (Sterculiaceae)	–	+	–	–
	Syzygium tawahense (Myrtaceae)	+	+	+	+
	Allanthospermum borneensis (Simaroubaceae)	–	+	–	–
	Cynometra elmeri (Caesalpiniaceae)	+	–	–	–
	Drypetes kikir (Euphorbiaceae)	–	–	+	–
	Eusideroxylon zwageri (Lauraceae)	–	–	–	+
	Hopea cernua (Dipterocarpaceae)	–	+	+	–
	Hopea semicuneata (Dipterocarpaceae)	+	–	–	–
	Shorea inappendiculata (Dipterocarpaceae)	–	+	–	–
	Teijsmanniodendron coriaceum (Verbenaceae)	+	–	–	–
	Vatica nitens (Dipterocarpaceae)	–	+	–	–

Abundance was defined as the presence of at least 10 stems per hectare on average in the subplots. After each species name it was abundance in the location of study areas in the primary forest site and three selectively logged forest sites: logged 10 years, 5 years, and 1 year ago, present (+) and not present (–).

Plant Functional Types expressed as tree densities

Stems of all PFT classes contributed importantly to tree densities, but there were pronounced differences across the forest types studied (Figure 3.3; Table 3.5).

For the heavy hardwood PFT, abundance of stems was significantly lower in the forest sites selectively logged 1 and 5 years ago than in the primary forest site. The light hardwood PFT class, expressed as abundance of stems, was higher in the forest sites selectively logged 1 year ago than in the primary forest site, with the value for the forest site selectively logged 1 year ago significantly higher than all other forest sites (Table 3.5). The medium hardwood PFT class, expressed as abundance of stems, was significantly less abundant in the forest sites selectively logged 1 and 10 years ago than in the primary forest site; there was no significant difference between the forest site selectively logged 5 years ago and the primary forest site (Table 3.5).

There were no significant differences in species numbers of the light hardwood PFT class between the selectively logged and the primary forest sites (Table 3.5). Generally, the percentage of smaller stems (10–60 cm dbh) in the light hardwood PFT class was low in the primary forest site (c. 15%) but twice as high in the selectively logged forest sites (Figure 3.3a-e). In addition, the percentage of larger stems (> 60 cm dbh) in the light hardwood PFT class was higher in

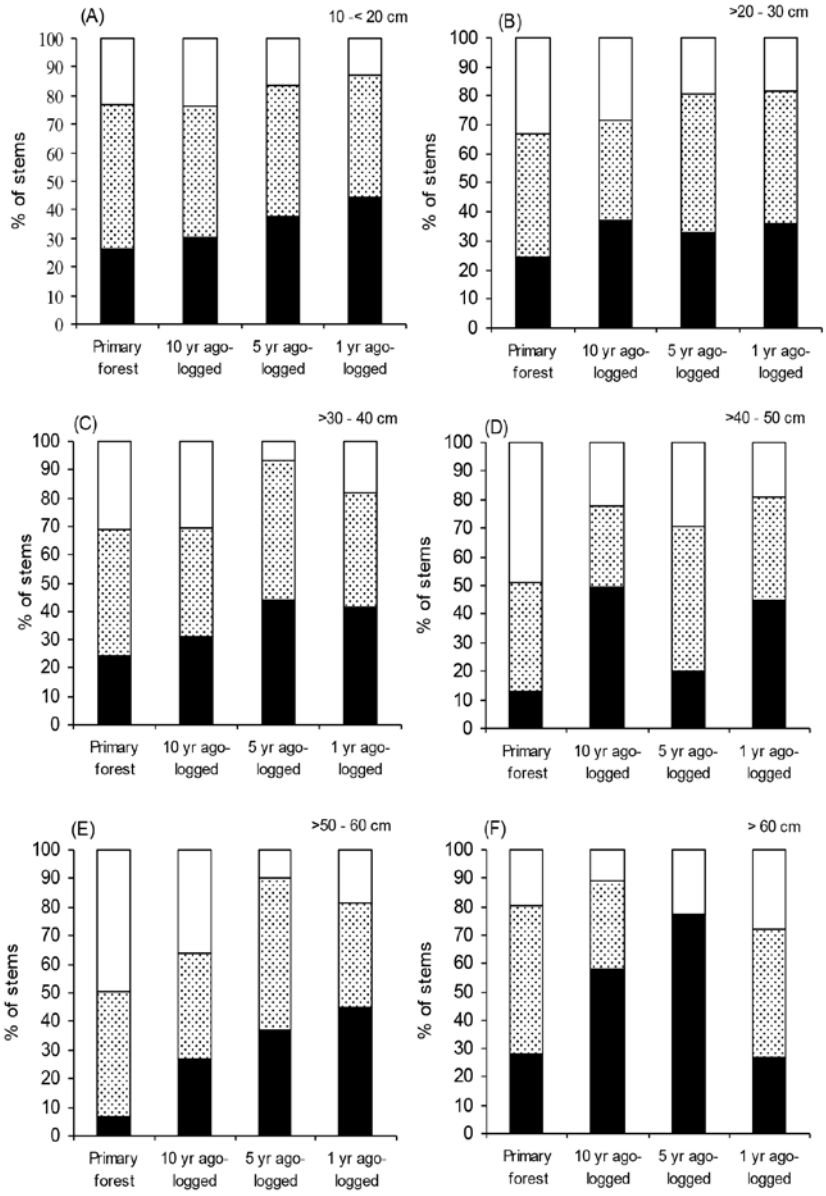

Figure 3.3
The classes of plant functional types light hardwood (solid bars), medium hardwood (cross-hatched), and heavy hardwood (open bars) of stems between 10–<20 cm dbh (A), >20–30 cm dbh (B), >30–40 cm dbh (C), >40–50 cm dbh (D), >50–60 cm dbh (E), and > 60 cm dbh (F) in the primary forest site, and selectively logged forest sites: logged 10 years, 5 years, and 1 year ago.

Table 3.5
Comparison between the plant functional type and species richness (average ± standard deviation) for all tree (dbh ≥ 10 cm) life forms and forest sites.

Plant functional type	Abundance stems (per 100 m²)				Species (per 100 m²)				Total species number			
	Primary Forest	Selectively logged forest			Primary forest	Selectively logged forest			Primary forest	Selectively logged forest		
		10 years ago	5 years ago	1 year ago		10 years ago	5 years ago	1 year ago		10 yrs ago	5 yrs ago	1 yr ago
Light hardwood	0.99 ± 1.03	1.29 ± 0.99	1.25 ± 1.11	**1.39 ± 1.33**	0.97 ± 0.98	1.23 ± 0.91	1.18 ± 1.01	1.25 ± 1.09	53	53	59	61
Medium hardwood	1.96 ± 1.44	**1.48 ± 1.36**	1.55 ± 1.33	**1.40 ± 1.28**	1.81 ± 1.28	1.34 ± 1.13	1.40 ± 1.19	1.32 ± 1.18	72	44	59	73
Heavy hardwood	1.13 ± 1.08	0.95 ± 1.03	**0.54 ± 0.82**	**0.49 ± 0.83**	0.90 ± 0.80	0.88 ± 0.93	**0.49 ± 0.73**	**0.43 ± 0.69**	22	24	21	22

Abundance expressed as densities of stems exceeding 1.3 m in height. Species richness at the subplot scale expressed as species number per subplot and at the landscape scale as the total observed species numbers in all subplots together in the primary forest site and three selectively logged forest sites: logged 10 , 5, and 1 year ago, in 10 x 10 m plots, covering a total of 1.5 ha. **Bold** averages for selectively logged forest sites differ significantly from those of the primary forest site (with Bonferroni correction for multiple tests)

the forest site selectively logged 5 years ago than in all other forest sites (Figure 3.3f). In the selectively logged forest sites, the dominant species in the light hardwood PFT class were *Alseodaphne elmeri* (Lauraceae), *Barringtonia macrostachya* (Lecythidaceae), *Gymnacranthera farquhariana*, *Horsfieldia polyspherula*, *Knema laurina*, *Myristica villosa* (all Myristicaceae), *Macaranga gigantea*, *Neoscortechinia kingii* (both Euphorbiaceae), *Shorea parvifolia* and *Shorea pinanga* (both Dipterocarpaceae).

The stem abundance in the medium hardwood PFT class was significantly lower in the forest sites selectively logged 1 and 10 years ago than in the primary forest site (Table 3.5). In addition, selective logging did not appear to affect the partitioning of stems across PFT in all forest sites. Only the > 60 cm dbh class in the medium hardwood PFT class was almost completely absent in the forest site selectively logged 5 years ago (Figure 3.3f).

The abundance of stems and species in the heavy hardwood PFT class was significantly lower in the forest sites selectively logged 1 and 5 years ago than in the primary forest sites (Table 3.5). This difference was most pronounced for the percentage of stems (Figure 3.3a-e), whereas for trees > 60 cm dbh the number of stems in the forest sites selectively logged 1 and 5 years ago was higher than in the primary forest site and lower than in the forest site selectively logged 10 year ago (Figure 3.3f).

Discussion

Changes in the forest structure after selective logging

Our study demonstrated that logging had a significant effect on the tree species richness and tree abundance in the diameter class up to 30 cm dbh (Table 3.2, 3.3). Logging did not affect tree species richness and tree abundance in trees >30–70 cm dbh. However, we found that there was a significantly lower number of species and a lower stem abundance for trees >70–80 cm dbh in the selectively logged forest sites 1 and 5 years ago (Table 3.2, 3.3). At larger diameters (>80 cm) dbh values became fuzzy and differences could no longer be detected. This was also reported by Verburg and Van Eijk-Bos (2003). With respect to our finding that logging history did not affect species richness and abundance for trees > 80 cm dbh, we point out that despite the fact that the removal of stems was similar in all selectively logged forest sites, we did observe a difference in the total damage expressed as number of stems between the forest sites selectively logged 1, 5 and 10 years ago (Table 3.1), which was possibly caused by the construction

of skidder roads. The effects of logging intensity could thus largely have been overshadowed by the damage caused by these roads, as has also been reported by Van Eijk-Bos (1996), Verburg *et al.* (2001), Slik and Eichhorn (2003) and Verburg and Van Eijk-Bos (2003). Because no data were available prior to logging, we could not analyze whether tree density in the selectively logged forest sites changed immediately according to the changes in landscape pattern in the recovering forest after logging (Verburg & Van Eijk-Bos, 2003). Our results on the impact of logging on tree species richness are similar to those of other studies carried out during forest inventories in East Kalimantan (Slik *et al.*, 2002; Slik & Eichhorn, 2003; Verburg *et al.*, 2001; Verburg & Van Eijk-Bos, 2003), although a study conducted in the Budongo forest reserve in Uganda showed an increase in species richness following logging activities (Plumtre, 1996).

The number of stems in the >70–80 cm dbh class was clearly affected in some selectively logged forest sites. Nonetheless, the effect of the removal of trees with large stems on forest structure and species diversity was hardly detectable, which could be an indication that diversity in species indices is not a valid tool for measuring the impact of logging in tropical lowland rainforest (e.g. Ter Steege *et al.*, 2002; Slik *et al.*, 2002; Verburg & Van Eijk-Bos, 2003). The impact of logging on tree density, however, depends strongly on the total number of tree stems and species that are removed (Slik *et al.*, 2002; Verburg & van Eijk-Bos, 2003). Although differences between the selectively logged and primary forest sites in stem density were not statistically detectable, based on the lower mean BA values in selectively logged versus primary forest sites, we may conclude that some species could disappear despite selective logging practices (Figure 3.2). The gap phase regeneration hypothesis has recently been under criticism as a mechanism to maintain species diversity due to new empirical evidence that shows tree fall gaps only cause a marginal increase in species diversity. Selective logging provides gaps that might enable light dependent on open places to become established tree pioneer species (e.g. Hubell *et al.*, 1999; Hubell, 2001; Verburg & Van Eijk-Bos, 2003).

Tree species composition in different diameter classes

Our study shows that tree species richness in the 10–<20 cm dbh class was lower in the forest sites selectively logged 5 and 10 years ago compared to the primary forest site, but higher in the forest site selectively logged 1 year ago (Figure 3.2b). Up to 60 cm dbh, the tree species richness was higher in the selectively logged than in the primary forest sites. Although patterns in tree species composition were very difficult to detect, we did find differences in replacement of stems between different wood density classes. Similar to our study, Verburg and Van Ei-

jk-Bos (2003) found a high fraction in the light hardwood class for a number of trees in the smallest diameter class. The higher species richness we found for the dbh class up to 60 cm was associated with the presence of pioneer species, such as the fast growing *Macaranga gigantea*, which were particularly abundant in the forest site selectively logged 10 years ago but absent in the primary forest site (Table 3.4). As was suggested by Slik *et al.* (2002), Slik and Eichhorn (2003) and Verburg and Van Eijk-Bos (2003), the stem recruitment of some pioneer species into the smallest diameter class after logging is most likely the result of the removal of adult tree stems and some species due to the construction of skidding trails or illegal logging activities. The regeneration of tree species in the selectively logged forest sites will mainly determine the prospects for recovery of the original plant diversity. Recently, Arbainsyah et al. (2014) found a high tree species richness in FSC candidate, selectively logged forest in East Kalimantan.

Several studies have reported on species composition in tropical rainforest (e.g. Austin, 1977; Newbery *et al.*, 1996; Sheil, 1999; Slik *et al.*, 2002). However, the effects of selective logging on forest structure in terms of the number of tree species per diameter class and plant functional types have rarely been studied. Ward's cluster analysis to separate selectively logged forest sites from primary forest site by the partitioning of life forms (i.e. trees, lianas, fern, shrubs and herbs) was used by Ek (1997) and Arbainsyah *et al.* (2014). They suggest that tree succession in primary tropical rainforest shows a clear intrinsic convergent trend, as was found in Uganda (Sheil, 1999). However, the end stage of this forest succession series was a mono-dominant tree stand which was relatively species-poor. Moreover, in Sheil's (1999) study in Uganda, primary succession was the control site and no replicate plots were used. In our study we did use replicates, but an analysis of tree species richness and tree abundance in the different tree diameter and PFT classes showed that these parameters varied widely across the forest sites considered. This finding suggests that studies involving chronosequences of selective logging may be difficult to interpret, because forest sites with different logging regimes do not necessarily have equal initial states, as shown by our study. This was also reported also by Verburg and Van Eijk-Bos (2003).

Changes in Plant Functional Types after selective logging

Our analyses of the smallest diameter class, < 30 cm dbh, showed a high contribution by the light hardwood PFT class in the abundance of stems from typical pioneer species after logging. Similarly, the abundance of light hardwood stems for > 60 cm dbh was relatively high in forest sites selectively logged 1 and 5 years ago. A delayed recruitment of the medium hardwood PFT class at > 60 cm dbh class was recorded in the forest site selectively logged 5 years ago. This is partly

the result of the differences in the fractions of PFT among logged plots, as has also been reported by Brown and Lugo (1990) and Verburg and Van Eijk-Bos (2003) who described secondary succession in terms of replacement of stems of different PFT classes. The increased contribution of light hardwood types in the selectively logged forest sites was confirmed with the relatively low abundance of medium hardwood stems. The heavy hardwood PFT class was less affected by the history of logging in the selectively logged forest sites. Although these patterns were confirmed by significant differences among the heavy hardwood PFT class in the selectively logged forest sites, they are partly the result of large differences in the classification of PFT among selectively logged forest sites. Secondary succession has also been described in terms of replacement of tree stems of different tree density classes (Brown & Lugo, 1990; Verburg & Van Eijk-Bos, 2003). Similar to our study, several authors found high stem abundances of light hardwood species during the first years of forest recovery succession (Brown & Lugo, 1990; Slik *et al.*, 2002; Verburg & Van Eijk-Bos, 2003).

The primary forest site contained a large density of heavy hardwood stems in the 40–60 cm dbh class, which was mainly the result of high numbers of *Hopea semicuneata* and *Teijsmanniodendron coriaceum*. These species were almost absent in the selectively logged forest sites. The selectively logged forest sites had a larger density of light hardwood stems compared to the primary forest site, including stems of *Shorea parvifolia* (Table 3.4), which is one of the main Dipterocarp timber trees that may have been a target species for logging in Kalimantan (Verburg & Van Eijk-Bos, 2003). In the light hardwood PFT class, trees with large diameters appeared to be affected considerably by logging, while trees with small diameters were still abundant in most of the selectively logged forest sites. Further regeneration of this PFT class depends on available stock of small stems of seedlings and saplings in the selectively logged forest sites (Arbainsyah *et al.*, 2014).

Conclusion

Our study shows that selective logging in tropical rainforests mainly affects the smallest tree stems up to 30 cm dbh, of the forest understorey and mid-levelstorey, and trees with stems between 70 and 80 cm dbh of the emergent trees in the upperstorey, with a clear negative relation between tree stem diameter and plant functional types. Our study showed significant differences between the abundance of tree stems in the small diameter class and in tree species richness in the selectively logged forest sites compared to the primary forest site. Our study revealed marked tree survival patterns, both in relation to stem diameter and PFT class. In the selectively logged forest sites, this PFT related pattern might also

result in selective extinction of certain tree species/genera because of differences in the tree species composition among PFT classes. It is therefore likely that, although tropical rainforests seem to be able to recover from selective logging to some extent, their species composition is altered considerably for a long time after logging took place. Recent evidence from our study area suggests that an undisturbed period of c. 10 years can benefit the recovery of biodiversity within selectively logged forest sites (Arbainsyah *et al.*, 2014). Since tree species diversity remained at an acceptable level throughout the selectively logged forest sites, protection of the primary forests could be worthwhile, especially considering the current rapid loss of primary forests in Southeast Asia.

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4

Avian community responses to selective logging in FSC-candidate tropical rain forests

Journal of Oryx (submitted)

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Abstract

The aim of our study was to analyze the impact of selective logging on bird communities in East Kalimantan. Our study compared secondary with primary lowland dipterocarp rainforest sites. The secondary forest sites were selectively logged in 2003, 2007 and 2011, in a forest concession which was in the process of FSC certification, in the Berau district. An additional non-certified disturbed forest site was included, the Pusrehut forest, which was situated in the Kutai Kartanegara region. The two primary forest sites were selected in the Berau district, and in the Sungai Wain protected forest in Balikpapan. We found no significant differences in species richness or Shannon diversity of bird communities between the different types of forests. However, we found a significantly higher abundance of birds in primary forests compared to non-primary forest sites. In particular, we found a higher abundance of birds classified as feeding on the ground in the terrestrial foraging layer in primary forests as compared to secondary forests. We also found a significantly higher abundance of birds of the frugivorous / insectivorous guild in the primary forest. Our results indicate that primary forests more effectively support the existing bird populations than forests that are selectively or non-selectively logged. Our results also show that selective logging practices, as implemented according to the certification process, are unlikely to be harmful to bird diversity and could thus be implemented alongside proper bird conservation measures.

Key words: Bird guilds, Sustainable forest management, Selective logging, Species composition, Species diversity, Southeast Asia.

Introduction

Logging and forest transformation forms a major threat to the biodiversity of the last remaining areas of undisturbed lowland tropical rainforest in Kalimantan (Eichhorn *et al.*, 2006; Laurance, 2004; Meijaard *et al.*, 2005; Wielstra *et al.*, 2011). As a result of logging, oil palm development, and transformation of forests into agricultural fields, large areas of natural forest in Kalimantan have been destroyed (Eichhorn *et al.*, 2006; Meijaard *et al.*, 2005; Slik *et al.*, 2002; Van Nieuwstadt, 2002). During recent years, the Indonesian government has promoted certified timber production, following the international Forest Stewarship Council (FSC) and the national Lembaga Ekolabel Indonesia (LEI), in order to achieve Sustainable Forest Management (SFM). The impact of commercial FSC-certified logging on tree diversity and forest structure has been well studied (Arbainsyah *et al.*, 2014, 2015).

A number of studies have thoroughly investigated the impact of logging on tropical lowland forest bird communities (Felton *et al.*, 2008; Haugaasen *et al.*, 2003; Johns, 1996; Kinnaird & O'Brien, 1998; Pieterse & Wielstra, 2011; Slik & Van Balen, 2006), although a review by Van Kuijk *et al.* (2009) identified major knowledge gaps with respect to the effects of reduced impact logging (RIL) – as occurs under FSC certification – on biodiversity conservation. It is unclear whether short-term effects as identified in most of the studies mentioned above also apply during longer time scales. The degree by which FSC logging possibly supports higher tree and animal diversity compared to conventional logging at different time scales remains unknown or poorly quantified. Similarly, the possible reduction in different measures of biodiversity relative to protected primary rainforest remains poorly studied. Our current understanding of the impact of FSC certification, and especially of the long-term recovery processes in FSC-certified forests on bird communities, is severely limited. Therefore, more information regarding such impacts on bird communities in tropical lowland rainforests is urgently needed, especially in Southeast Asia (De Iongh *et al.*, 2005; De Iongh & Persoon, 2010; Ghazoul & Hellier, 2000; Slik & Balen, 2006;).

The Intermediate Disturbance Hypothesis (IDH) is one of the most frequently suggested non-equilibrium explanations for the maintenance of species diversity in ecosystems (Connell, 1978; Wilson, 1990; Roxburgh *et al.*, 2004). Gaps formed by selective logging under FSC certification or other forms of RIL are generally intermediate in terms of disturbance intensity, when compared to conventional logging (Roxburgh *et al.*, 2004). However, RIL may possibly still benefit early and mid-successional bird species more than that part of the avian community that relies on a well-developed and undisturbed litter layer of suf-

ficient spatial extent, as only occurs in undisturbed primary forest (Van Kuijk *et al.*, 2009). Bird biodiversity does not only respond to mild disturbance, it is most likely also critically dependent on large and diverse natural habitats (Slik & Balen, 2006).

Avian communities have important ecosystem functions in tropical rainforests, such as pollination, seed dispersal and predation (Bibby *et al.*, 2000; De Iongh & Persoon, 2010; De Iongh & Van Weerd, 2006; Furness & Greenwood, 1993; Gray *et al.*, 2007; Stiles, 1983) and they could potentially be a suitable taxonomic group for assessing and monitoring the impact of logging on biodiversity in tropical lowland rainforests (Edwards *et al.*, 2009; Johns, 1991; Van der Hoeven *et al.*, 2000; Wielstra *et al.*, 2011). Avian community composition can be strongly influenced by logging disturbance of forest vegetation structure (Barlow & Peres, 2004b; Felton *et al.*, 2008; Mason & Thiollay, 2001; Slik & Balen, 2006; Wiens, 1992;) and bird species richness has been found to decline in response to logging (Felton *et al.*, 2008; Johns, 1991; Marsden, 1998; Thiollay, 1997), although some cases reported an increase (Johns, 1996; Kofron & Chapman, 1995). In some studies, avian communities became increasingly dissimilar from those in primary forest after logging and contained a higher abundance of avian species associated with secondary growth habitats (Barlow & Peres, 2004a; Slik & Balen, 2006). These changes in avifaunal assemblages were strongly associated with changes in the vegetation structure, such as canopy cover, undergrowth, and plant regeneration (Johns, 1991; Barlow & Peres, 2004b; Slik & Balen, 2006).

Differences in avian species composition between non-primary forests and primary forests are often more pronounced when individual guilds are examined (Bibby *et al.*, 2000; Ghazoul & Hellier, 2000). The abundance of insectivorous birds, for example, generally declines in secondary habitats, whereas nectarivore abundance and species richness may increase (Mason, 1996; Canaday, 1997; Pieterse & Wielstra, 2005). There is overwhelming evidence that logging primarily affects the understorey insectivorous guild (Johns, 1991; Van der Hoeven *et al.*, 2000).

Here we present an analysis of avian communities in East Kalimantan in forests that were selectively logged in 2003, 2007, 2011 versus a primary forest site and two external sites: the Sungai Wain forest site (a primary forest) and the Pusrehut forest site (a disturbed forest). Our main research question was: How do avian communities respond to disturbance by logging?

Materials and methods

Study area

The study area is located in tropical lowland forest within a forest concession which was in the process of being FSC certified, in the Berau district and two external sites: one primary forest site (Sungai Wain protected forest) and one disturbed non-FSC-certified forest site (Pusrehut). All sites are located in the province of East Kalimantan, Indonesia (Figure 4.1). In the Berau district, four sites were selected for data collection: one primary forest site and three selectively logged forest sites logged in 2003, 2007 and 2011. Near the city of Balikpapan a site of primary forest was selected in the Sungai Wain Protected forest. In the district of Kutai Kartanegara a disturbed site was selected in the Pusrehut forest. This site had been logged in the 1970s, suffered moderate to heavy burning in 1982/1983 and was then replanted with indigenous tree species. It was logged in 1996 and heavily disturbed by fires again in 1997 and 1998. This site had been exposed to considerable illegal logging activities in the period from 1998 to 2014 (Table 4.1).

In the Berau district, the altitude range at the study area is 25-140 m above sea level (Mantel *et al.*, 2002). The topography of all sites consists of a rolling hilly landscape with shallow valleys and gullies. In the Sungai Wain protected forest, the altitude range at the study area is 40-90 m asl (Slik & Eichhorn 2003). In the Pusrehut forest, the altitude range at the study area is 85-140 m asl (Slik & Eichhorn, 2003).

The three forest types were adopted according to FAO (2001): 1) Primary forest is defined as a forest that has been logged more than 30 years ago or has never been logged; 2) Selectively logged forest is defined as forests with specific areas where the trees have been removed less than 30 years ago as a result of harvesting or logging, and where the forest is expected to regenerate naturally or with the aid of silvicultural measures; 3) Disturbed forest is defined as forest containing significant areas which have been exposed to human disturbance, including clearing, harvesting or logging, felling for wood extraction, hunting, anthropogenic fires and road construction.

Bird surveys

Within each of the study sites five sampling points were identified at a distance of 200 m from each other and these were used for point counts to assess the presence of individuals of different bird species (Bibby *et al.*, 2000). Point counts are

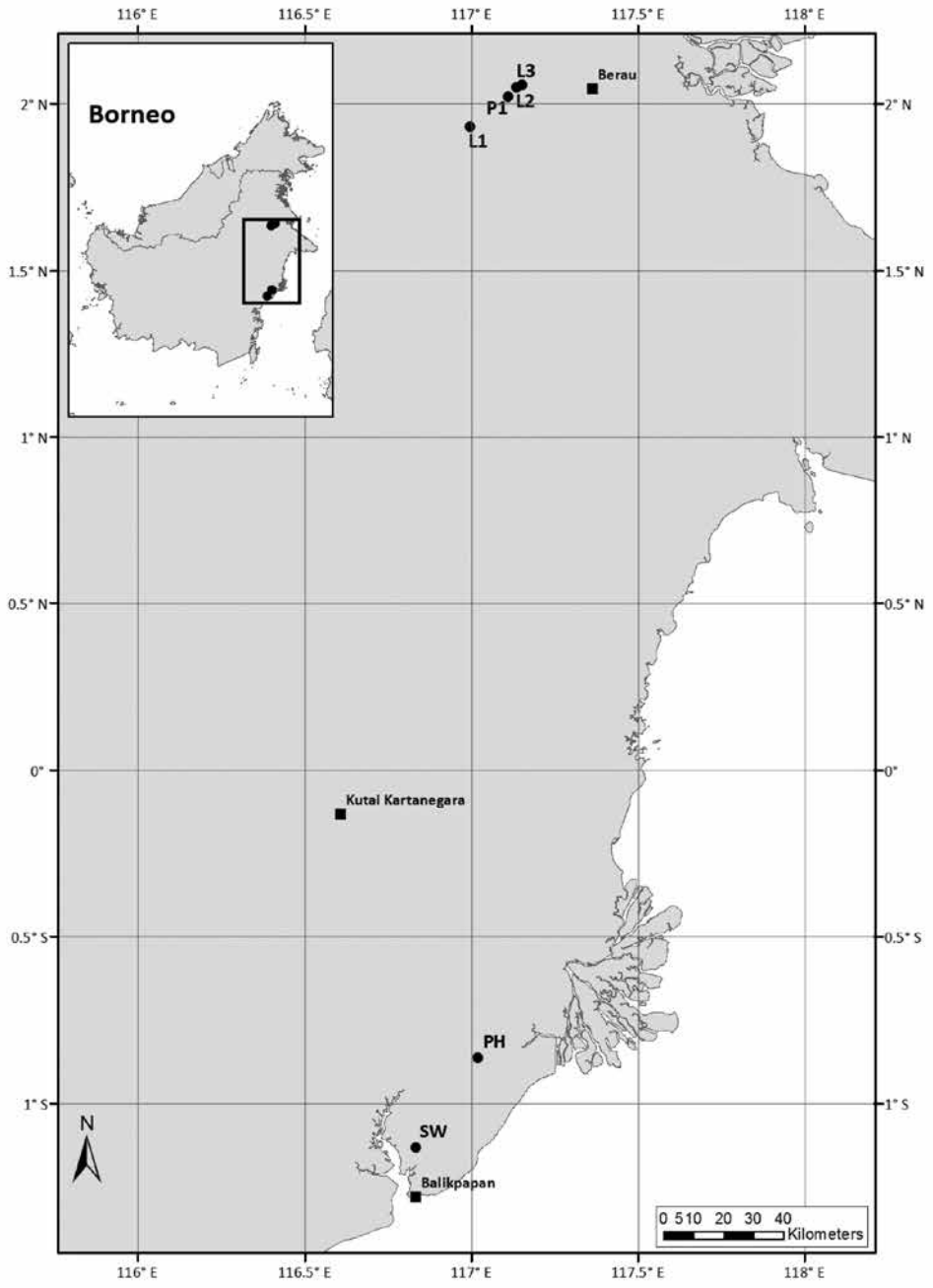

Figure 4.1
Map of East Kalimantan with the location of study areas P1 point counts: primary forest site, L1 point counts: logged in 2011, L2 point counts: logged in 2007, L3 point counts: logged in 2003, SW point counts: Sungai Wain forest site (primary forest), PH point counts: Pusrehut forest site (disturbed forest).

generally preferred as a counting method in dense forests, because they are suggested to cause less disturbance in comparison to e.g. transect counts and offer the possibility to include auditory observations (Bibby *et al.*, 2000). Observations were done in all sites between February and August 2014, at 30 locations in total: 2 × 5 in primary forest, 15 in FSC-candidate, selectively logged forest sites, and 5 in the disturbed non-FSC-certified forest site (Table 4.1).

Counts were repeated four times during mornings (at dawn) and late afternoons (at dusk), each on subsequent days, based on Slik and Balen (2006) (Table 4.1). The observations were made by the 1st, 4th and 5th authors of this paper and a bird expert from the University of Mulawarman, Samarinda. Morning visits usually started around 06h and afternoon visits around 16h, each visit lasting approximately 2 hours. During a site visit all five sampling points were surveyed for 15 min each (following Pieterse & Wielstra, 2005) and all individual birds seen and heard were recorded. No distance limitation was used, but the bias caused by this was considered similar for all sites. We also used a microphone placed on a tripod to record all the bird sounds for later identification using reference bird sounds and help from a Dutch birds expert (Dr. Bas van Balen) and two Indonesian bird experts (Agus Prastiono and Satriyo Susito). In order to allow birds to return after being scared away when approaching, counts started 2 min after reaching each observation point. To minimize a possible bias occurring from visiting the points at the same time of day, the points were visited in a reversed order during alternating visits. Counts were not conducted during rainfall because of the inactivity of birds during such weather conditions (Bibby *et al.*, 2000; Slik & Van Balen, 2006). Throughout this study, each bird species was assigned to one of the bird guilds based on Wielstra *et al.* (2011).

Data analyses and statistics

For analysis, a data set was created that contained the following dependent variables per point count location: 1) 'Total species': all species encountered during the eight visits; 2) 'Mean abundance': the average number of individuals per visit; 3) 'Mean species': the average number of species per visit; 4) 'Shannon index': the Shannon diversity index over all eight visits; 5) 'Evenness index': the Pielou evenness index over all eight visits (Table 4.2). The 'Shannon index' was exponentially transformed before analysis, following Jost (2006). The six forest sites were compared with respect to the above parameters. As our point counts were regarded as randomly selected within the forest sites, forest sites were randomly selected from within the regions, and the regions were a random selection from all possible regions in East Kalimantan, the use of a mixed linear model in which

the region is the random effect variable was justified. For all parameters, residuals were checked, except for 'Total species' for which we had to apply a generalized linear mixed model with Poisson residual distribution. All our models were maximum random effect models, i.e. including the effects on both the intercept and the regression coefficient (Barr *et al.*, 2013).

Secondly, we analyzed whether primary forests were different from non-primary forests for all of the dependent variables. In this case, we assumed that all our forests were a random selection out of all possible forests. Again, we applied a linear mixed model, but now with 'Forest' as the random effect variable. Again, residuals were checked and only in case of 'Total species' we needed to assume a Poisson distribution of the residuals.

Next, based on Wielstra *et al.* (2011), the birds were classified into two feeding classes: 1) foraging layer (T = terrestrial; U = understorey; A = arboreal) and 2) diet (N = nectarivore ; F = frugivore ; FI = frugivore / insectivore ; FC = frugivore / carnivore ; I = insectivore ; IC = insectivore / carnivore). For each of these guilds the average over the eight visits of the abundance per point count was calculated. The difference between primary and non-primary forests between these 'Mean abundances per guild' were again analyzed with a linear mixed model for which 'Forest' was included as random effect variable.

For testing, we applied in all cases a Likelihood-Ratio Test (LRT). We performed the statistical analyses using R software (version 3.1.1, R Development Core Team 2014). For the mixed models, we used lmer () of the package lme4 (Bates 2014), version 1.1-7. We constructed species rarefaction curves (nrandom = 499) using the package rich in R (Rossi 2011).

Results

General findings

A total of 154 species were observed during the field work covering all 6 forest sites, with 84 species in the Berau primary forest site, 84 species in the Berau forest site that was selectively logged in 2003, 76 species in the Berau forest site that was selectively logged in 2007 and 80 species in the Berau forest site selectively logged in 2011, 76 species in the Sungai Wain primary forest and 76 species in the disturbed Pusrehut forest site (Table 4.1).

Table 4.1
Number of point counts, point count visits and total number of species per forest type per location (see also figure 4.1).

Location	Forest types	Point counts	Point count visits	Total species
Berau	Primary forest1	5	8	84
Sungai Wain	Primary forest2	5	8	76
Berau	Selectively logged in 2003	5	8	84
	Selectively logged in 2007	5	8	76
	Selectively logged in 2011	5	8	80
Pusrehut	Disturbed forest	5	8	76

Table 4.2
The difference between primary forests and non-primary forests; * = $p < 0.05$; NS = not significant.

Location / Forest types (sites)	Point Counts	Total Species	Mean Abundance	Mean Species	Shannon Index	Evenness Index
Berau						
▪ Primary forest1	1	45	13.88	11.63	3.57	0.94
	2	50	16.63	12.25	3.61	0.92
	3	34	11.50	9.75	3.26	0.92
	4	39	11.63	9.88	3.38	0.92
	5	45	13.00	10.00	3.59	0.94
SungaiWain						
▪ Primary forest2	1	38	9.88	8.63	3.46	0.95
	2	43	12.88	10.13	3.41	0.91
	3	37	15.00	10.13	3.19	0.88
	4	34	13.13	9.13	3.16	0.90
	5	43	12.88	10.00	3.46	0.92
Berau						
▪ Logged 2003	1	39	10.25	8.25	3.51	0.96
	2	45	13.00	10.63	3.54	0.93
	3	43	14.00	10.25	3.54	0.94
	4	31	9.50	7.63	3.12	0.91
	5	40	11.63	9.38	3.45	0.94
▪ Logged 2007	1	35	10.13	8.38	3.30	0.93
	2	34	10.25	7.88	3.20	0.91
	3	39	10.63	9.13	3.50	0.95
	4	32	8.38	7.00	3.28	0.95
	5	32	8.25	7.00	3.28	0.95
▪ Logged 2011	1	34	9.38	7.63	3.29	0.93
	2	36	11.63	9.25	3.32	0.93
	3	35	8.50	7.25	3.35	0.94
	4	44	14.50	10.50	3.49	0.92
	5	40	12.38	9.50	3.33	0.90

Table 4.2 (continued)

Pusrehut						
▪ Disturbed forest	1	37	11.50	9.50	3.33	0.92
	2	42	10.75	9.00	3.59	0.96
	3	32	11.25	9.75	3.17	0.91
	4	31	7.13	6.50	3.29	0.96
	5	37	8.88	8.00	3.47	0.96
p-values LRT-test		0.1136 (NS)[a]	0.01483 (*)	0.0393 (*)	0.4692 (NS)[b]	0.1291 (NS)
p-values LRT-test with correction for ln (Mean Abundance)				0.2862 (NS)		

[a]: assumed poisson distribution

[b]: after exponential transformation

We did not find a significant difference between the six forest sites for 'Total species', 'Mean abundance', 'Mean species', 'Shannon index' or 'Evenness' (results not presented). When comparing the primary forests with the non-primary forests, we did not find significant differences in 'Total species' or the two diversity indices (Shannon and Evenness indices) (Table 4.2). However, we found a significantly higher mean abundance per visit per site ($P = 0.015$) and mean species richness per visit ($P = 0.040$) in the primary forests than in the non-primary forests (Table 4.2, Figure 4.2). As the higher mean species numbers in primary forests could possibly result from a higher mean abundance in the primary forests, we checked the influence of abundance on species richness by executing a rarefaction analysis (Figure 4.3). The result shows that the rarefaction curve for the primary forests was below that of the curve for secondary forests.

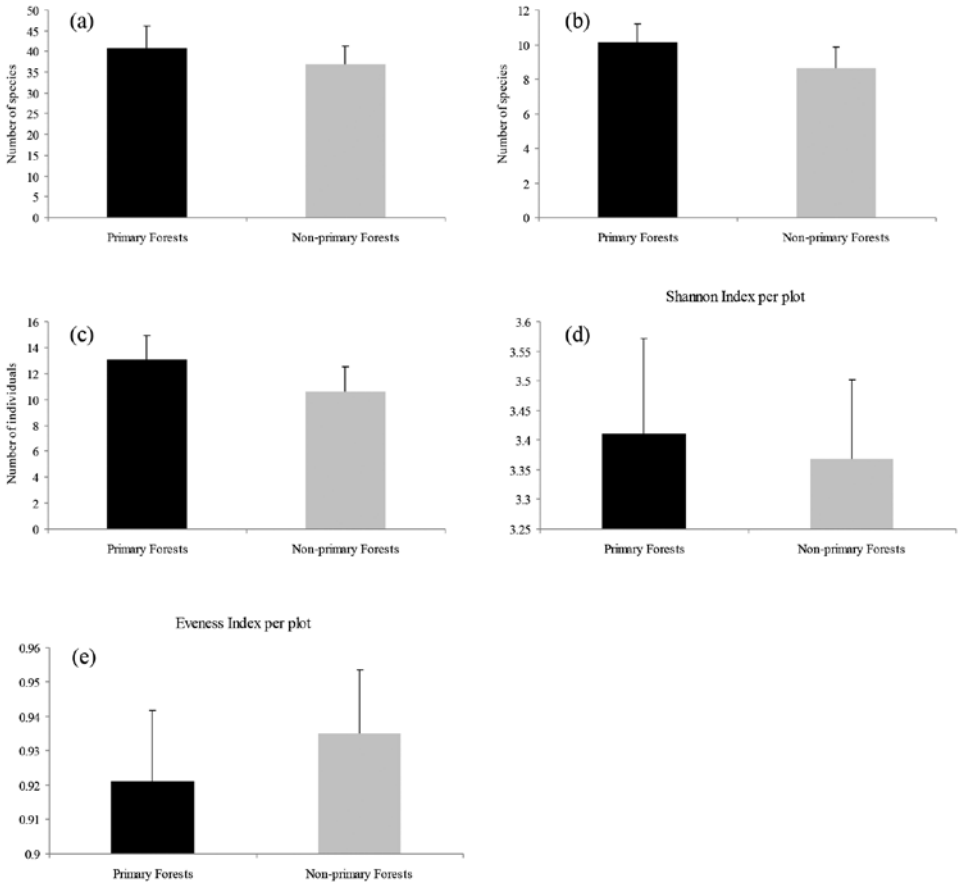

Figure 4.2
Species richness per plot (a), species richness per observation (b), abundance per observation (c), Shannon index per plot (d) and evenness index per plot (e) of birds in the primary forests (black) and non-primary forests (grey).

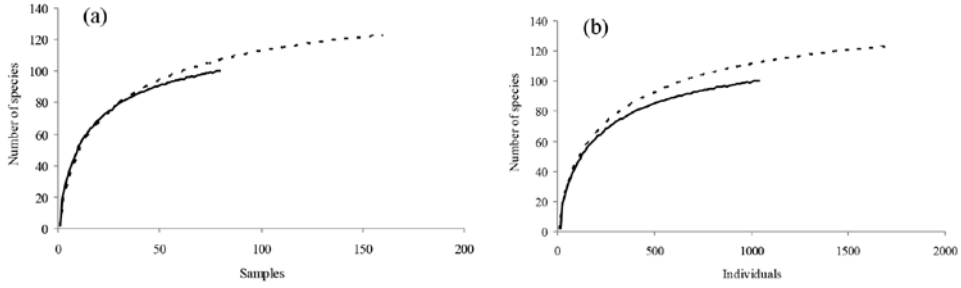

Figure 4.3
The rarefaction curves of the sample of bird species (a) and number of bird individuals (b) in the primary forest sites (line) and non-primary forest sites (dashed line).

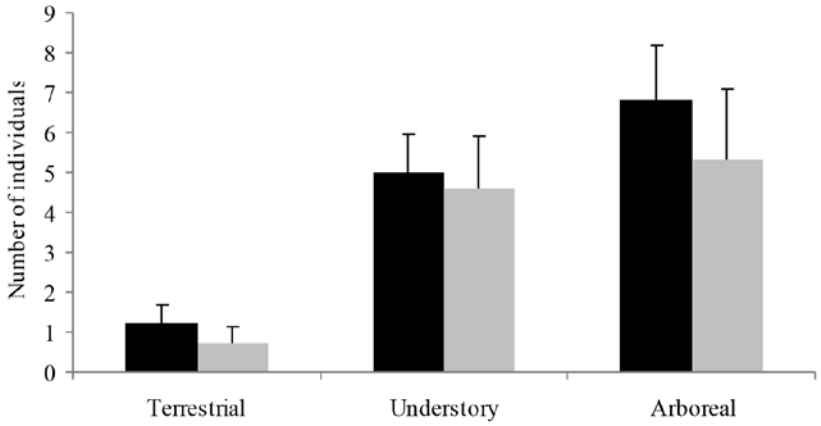

Figure 4.4
Mean abundance (plus standard deviation) per foraging layer guild in the primary forest sites (black) and non-primary forest sites (grey).

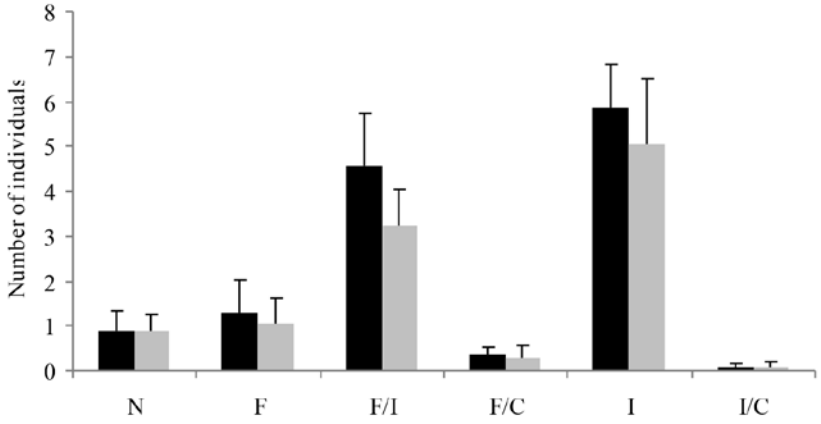

Figure 4.5
Mean abundance (plus standard deviation) per diet guild: Nectarivore (N), Frugivore (F), Frugivore/insectivore (F/I), Frugivore/carnivore (F/C), Insectivore (I), Insectivore/carnivore (I/C) in primary (black) and non-primary forest sites (grey).

Table 4.3
The difference between primary and non-primary forest sites in abundance per foraging layer guild: terrestrial, understorey and arboreal birds per visit per site; * = p < 0.05); . = p < 0.1; NS = not significant.

Location / Forest types (sites)	Point counts	Mean Terrestrial	Mean Understory	Mean Arboreal
Berau				
▪ Primary forest1	1	1.875	4.5	7.5
	2	0.75	6.375	9.5
	3	0.5	4.875	6.125
	4	1.375	4.75	5.5
	5	1.125	5.875	6
SungaiWain				
▪ Primary forest2	1	1.375	4	4.5
	2	1.875	3.75	7.25
	3	1	6.5	7.5
	4	1.25	4.375	7.5
	5	1.125	5.125	6.625
Berau				
▪ Logged 2003	1	0.75	3.25	6.25
	2	1	5.125	6.875
	3	0.25	5.5	8.25
	4	0.25	6.625	2.625
	5	0.25	4.25	7.125
▪ Logged 2007	1	0.125	2.375	7.625
	2	0.875	5.25	4.125
	3	1	4.125	5.5
	4	1.125	2.5	4.75
	5	0.5	3.625	4.125
▪ Logged 2011	1	0.125	2.25	7
	2	0.875	4.75	6
	3	0.25	4.125	4.125
	4	0.625	6.25	7.625
	5	0.625	5.75	6
Pusrehut				
▪ Disturbed forest	1	1.25	5.625	4.625
	2	1.5	4.875	4.375
	3	1.375	6.75	3.125
	4	0.875	3.875	2.375
	5	0.5	4.75	3.625
p-values LRT-test		0.01894(*)	0.3721	0.05428(.)

Table 4.4
The difference between primary and non-primary forest sites in abundance per diet guild: nectarivore, frugivore, frugivore/insectivore, frugivore/carnivore, insectivore and mean insectivore/carnivore birds per visit per site; ** = p < 0.01); NS = not significant.

Location / Forest types (sites)	Point counts	Mean Nectarivore	Mean Frugivore	Mean Frugivore/ insectivore	Mean Frugivore/ carnivore	Mean Insectivore	Mean Insectivore/ carnivore
Berau							
▪ Primary forest1	1	1.125	0.5	6.125	0.25	5.625	0.25
	2	1.25	2.75	4.875	0.25	7.5	0
	3	1.125	0.75	4.625	0.25	4.625	0.125
	4	1.25	1.5	3.25	0.375	5.25	0
	5	1.375	0.875	3.75	0.625	6.125	0.25
SungaiWain							
▪ Primary forest2	1	0.375	1	3.125	0.25	5.125	0
	2	0.75	0.75	4	0.25	7.125	0
	3	0.125	1.5	6.5	0.125	6.75	0
	4	1.125	2.375	4.125	0.375	5.125	0
	5	0.5	0.75	5.375	0.75	5.5	0
Berau							
▪ Logged 2003	1	1.125	1.375	2.625	0.5	4.5	0.125
	2	0.75	0.875	3.875	0.25	7.125	0.125
	3	0.875	1.5	4.375	0.375	6.625	0.25
	4	1.625	1	4	0.125	2.75	0
	5	0.75	1.875	4.375	0.5	4.125	0
▪ Logged 2007	1	0.625	1.5	3.875	0.125	4	0
	2	1.25	0.625	3	0.375	5	0
	3	1	0.375	2.625	0.375	6.25	0
	4	1	0.25	2.25	0.25	4.5	0.125
	5	1.125	0.625	2.625	0.125	3.75	0
▪ Logged 2011	1	0.25	1.5	2.75	0.375	4.25	0.25
	2	1	0.25	3.75	0	6.5	0.125
	3	0.75	0.25	2.25	0	5.25	0
	4	0.5	0.875	4.75	0.25	7.875	0.25
	5	0.5	0.875	3.5	0.125	7.375	0
Pusrehut							
▪ Disturbed forest	1	0.5	1.75	3	1.125	4.75	0.375
	2	0.75	1.375	2.875	0.5	5.125	0.125
	3	1.75	1.75	3.5	0	4.25	0
	4	0.75	1.375	1.625	0	3.125	0.25
	5	0.5	1.375	2.625	0.5	3.875	0
p-value LRT-test		0.8986	0.4208	0.00991(**)	0.5418	0.1378	0.4753

Table 4.5
List of feeding guild of bird species that are abundant in at least one of the forest sites. Abundant was defined as represented by at least 10 individual birds in the point counts; present (+) and not present (–).

Feeding guild	Species name	Berau (primary forest1)	Sungai Wain (primary forest2)	Berau, Selectively logged forest			Pusrehut (disturbed forest)
				in 2003	in 2007	in 2011	
Arboreal frugivore / insectivore	Alcippe brunneicauda	–	–	–	–	+	–
	Gracula religiosa	–	+	+	+	–	–
	Irena puella	+	–	–	–	–	–
	Megalaima australis	–	–	+	+	+	+
	Megalaima chrysopogon	–	–	–	–	+	–
	Megalaima henricii	–	–	–	–	+	–
	Megalaima mystacophanos	+	–	–	–	–	–
	Megalaima rafflesii	–	+	+	–	–	–
	Pycnonotus atriceps atriceps	–	+	–	–	–	+
	Pycnonotus simplex	–	–	–	+	–	–
Arboreal insectivore	Calorhampus fuliginosus	–	+	–	–	–	–
	Dicrurus aeneus	+	–	–	–	–	–
	Dicrurus paradiseus	–	–	–	–	+	–
	Eurylaimus ochromalus	+	+	+	+	+	+
	Hypothymis azurea	–	–	+	–	–	–
	Malacopteron magnum	–	–	–	+	+	–
	Platysmurus atterimus	–	+	–	–	–	–
	Trichixos pyrropygus	–	–	+	–	–	–
Terrestrial frugivore / insectivore	Megalaima eximia	–	+	–	–	–	+

Table 4.5 (continued)

Terrestrial insectivore	Pitta granatina	+	–	–	–	–	–
	Stachyris maculata	+	+	+	+	+	–
	Trichastoma malaccense	–	+	–	+	–	+
Understorey frugivore / insectivore	Dicaeum trigonostigma	–	–	–	–	–	+
	Pycnonotus brunneus	+	+	+	+	+	+
	Tricholestes criniger	+	–	–	–	–	–
Understorey insectivore	Macronous ptilosus	–	–	–	–	–	+
	Orthotomus atrogularis	–	–	–	–	–	+
	Stachyris erythroptera	+	–	+	+	+	–
Understorey nectarivore	Arachnothera longirostra	+	–	+	+	–	+

When correcting the mean species number for abundance by including the log transformed mean abundance in our model for mean species numbers, the mean species number was no longer significantly different between primary and secondary forests (Table 4.2).

We found a significant difference in the number of individual birds that are feeding on the ground in the terrestrial foraging layer between primary forests and non-primary forests. This guild showed a significantly higher mean abundance in the primary forest sites ($P = 0.019$) (Table 4.3, Figure 4.4). We also found a near significant difference in the arboreal guild between primary forests and non-primary forests. This guild also showed a (marginally) higher number of birds in the primary forests ($P = 0.054$) (Table 4.3).

With respect to guilds based on diet, we found that the frugivorous / insectivorous guild was significantly more abundant in the primary forest site ($P = 0.010$) as compared to secondary forest sites. None of the other guilds showed a significant difference in abundance between these two forest types (Table 4.4, Figure 4.5).

In the Berau primary forest, the bird species Asian fairy-bluebird (*Irena puella*), Red-throated barbet (*Megalaima mystacophanos*), Bronzed drongo (*Dicrurus aeneus*), Garnet Pitta (*Pitta granatina*) and Hairy-backed bulbul (*Tricholestes criniger*) dominated. In the Sungai Wain primary forest, the Bornean black magpie (*Platysmurus atterimus*) was the dominant bird species. These bird species were absent in the secondary forests (Table 4.5).

Discussion

Our study shows a significant difference in the mean abundance of birds observed per visit per site between two groups of forest plots: the primary forest sites had a higher number of individual birds than the secondary forest sites. This difference in abundance is probably related to the fact that the primary forest sites provide more food resources than the non-primary forest (Slik & Van Balen, 2006). Especially the reduction of trees in the secondary forest sites as a result of selective logging reduces the vertical resource availability for birds (Slik & Van Balen, 2006). Reduction in plant diversity and the strong dominance among small plants of only a few species through the growth of pioneer herbs, shrubs, lianas and trees also strongly reduces the availability of suitable habitat and may reduce resource availability through a change in the quality of vegetation structure (Arbainsyah *et al.*, 2014, 2015).

The number of individual birds per guild, when comparing the primary forests and secondary forest sites, showed some significant differences in terms of the abundance of guilds based on diet and preferred forest layer for foraging (Table 4.3 & 4.4). Our finding that the frugivorous / insectivorous guild was more abundant in the primary forest sites compared to secondary forest sites contradicts earlier studies in Borneo, where frugivorous / insectivorous guilds were more abundant in the secondary forest sites (Johns, 1996; Van Hoeven *et al.*, 2000; Pieterse & Wielstra, 2005; Wielstra *et al.*, 2011).

In the secondary forest sites the reduced availability of a foraging layer may result in a loss of food sources for certain bird guilds (Karr & Brawn, 1990; Mason, 1996; Pieterse & Wielstra, 2005; Slik & Balen, 2006). For example, birds that prefer foraging on the ground (terrestrial layer) were less abundant in secondary forests in the sites we studied (Table 4.4 & 4.5). This finding is similar to the finding of Gray *et al.* (2007) who also found a loss of terrestrial species. Some bird species may need a well-developed litter layer which has established over a long period and covers a sufficiently large spatial area (Van Kuijk *et al.*, 2009).

Illegal logging remains a serious concern that could seriously affect biodiversity in all remaining forest sites, including FSC-certified sites and protected primary rainforest sites. Local observations by the authors indicate that more effective measures need to be implemented to safeguard both protected and FSC-certified forests in Indonesia.

In conclusion, the differences we found between primary forests and secondary forests, particularly with respect to bird abundance, but also in feeding guild composition indicate that primary forests more effectively support the existing bird populations than forests that are selectively or non-selectively logged. It shows that a sustainable selective logging regime could be implemented alongside bird conservation measures in protected forests, without any major impacts on bird diversity.

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5

Diversity and abundance of endemic bird species in logged sites and primary rain-forest sites in East Kalimantan, Indonesia

Journal of Forktail (submitted)

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Abstract

The aim of our study was to analyze the impact of selective logging on Bornean endemic avian species in terms of abundance and species richness. Our study compared secondary forest sites with relatively undisturbed primary lowland dipterocarp rain forest sites of East Kalimantan. The secondary forest sites were located in the Berau district and were in the process of being FSC certified. At these sites, the forest had been selectively logged in 2003, 2007 and 2011. One additional non-certified disturbed secondary forest site was selected in the Pusrehut forest, in the Kutai Kartanegara region. The two primary forest sites were located in the Berau district and in the Sungai Wain protected forest in Balikpapan, respectively. We found a significantly higher abundance of insectivorous endemic birds in primary forests compared to the secondary forests, suggesting their vulnerability to selective logging. Selective logging did not have a clear effect on the diversity of endemic bird species in other feeding guilds.

Key words: Endemic avian Bornean species, Sustainable forest management, Selective logging, Species diversity, Southeast Asia.

Introduction

Logging activities in tropical rainforests lead to various degrees of forest destruction and subsequent habitat loss (Kartawinata, 1977; Skole & Tucker, 1993; Laurance, 1998; Parthasarathy *et al.*, 1999; Meijaard *et al.*, 2005), which in turn initiates a variety of ecosystem processes that could compromise populations of plants and animals (Meijaard *et al.*, 2005). Among the negative impacts of logging that have been reported are mortality of canopy trees due to edge effects (Laurance *et al.*, 2000; Wang *et al.*, 2006) and declines in bird abundance and/or diversity (Boulinier *et al.*, 2001; Beier *et al.*, 2002; Slik & Van Balen, 2006). Since tropical rainforests harbor most of the world's biodiversity, tropical deforestation has become a major cause of global species extinctions (Pimm & Raven, 2000). In disturbed forests, species richness may increase due to an increased number of common edge species (Johns, 1996). Species richness alone may therefore not be a good indicator for the status or recovery of forest biodiversity (Ghazoul & Hellier, 2000; De Iongh & Van Weerd, 2006; De Iongh & Persoon, 2010).

During recent years, the Indonesian government has promoted certified timber production through FSC and LEI in order to achieve Sustainable Forest Management (SFM). Although it is generally believed that such SFM practices are less harmful than conventional logging practices, van Kuijk *et al.* (2009) concluded that there are still serious knowledge gaps regarding their impact on e.g. biodiversity conservation.

The vegetation in later successional stages of forest ecosystems is usually taller and has a greater tree species richness compared to vegetation in an early successional stage (Linder *et al.*, 1997; Cochrane and Schulze, 1999; Wang *et al.*, 2006; Ding *et al.*, 2008). Vegetation in the late successional stage also tends to have higher variation in tree size, and more vertical layers (Linder *et al.*, 1997; Venier & Pearce, 2005). Such variations in habitat structure, including canopy cover, tree height and understorey regeneration, have been reported to be strongly associated with changes in avian communities (Barlow & Peres 2004; Oppel, 2006; Schieck & Song, 2006; Slik & Van Balen, 2006; Ding *et al.*, 2008; Arbainsyah *et al.*, 2015b).

One of the characteristics of avian communities in tropical areas is the high number of species classified as endemics (Anderson, 1994; Stattersfield *et al.*, 1998; Boer, 2006). Endemic avian species diversity is highly sensitive to disturbance in forests, such as logging (MacArthur & MacArthur, 1961; Henle *et al.*, 2004; Meijaard *et al.*, 2005). Meijaard *et al.* (2005) believes that there is an evolutionary explanation for the sensitivity of endemic bird species in Borneo to disturbance

of forests, which have evolved in rainforest refugia during multiple ice-age cycles. Terrestrial insectivores and low to mid understorey flycatchers are for instance consistently intolerant of logging and show a greater decline than other guilds after logging (Johns, 1989; Lambert, 1992; Thiollay, 1992). Among the bird guild of understorey insectivores, both the number of bird species that are present or absent and their proportional representation within the population sample decrease following logging at moderate intensities. Lambert (1992) reported trogons *Harpactes* spp., woodpeckers (Picidae), wren babblers (*Kenopia striata* and *Napothera* spp.) and flycatchers (*Cyornis* spp. and *Ficedula* spp.) as prone to decline in logged forests. Reported declines are suggested to be a reflection of the loss of understorey vegetation, foraging substrata and the associated cryptic insect prey that understorey insectivores specialize on (Robinson, 1969). Karr and Freemark (1983) reported that physiological conditions (i.e., high temperature and water stress) have a more significant impact than local food abundance in determining the ranging of some understorey species in Panamanian forests. Microclimatic conditions are altered by loss in tree canopy cover and understorey vegetation species are often reluctant to cross open spaces or dense secondary growth that separates remaining patches of primary forest (Meijaard *et al.*, 2005).

Based on these findings, we intend to test the hypothesis that endemic bird guilds are more sensitive to logging. We present a detailed analysis of the endemic avian species in East Kalimantan in forests that were selectively logged in 2003, 2007, 2011, a primary forest site and two external sites; the Sungai Wain forest site (a primary forest) and Pusrehut forest site (a disturbed forest). Our main research question was: What are the differences in endemic avian species diversity and abundance between selectively logged forest sites in comparison to primary forests?

Materials and methods

Study area

The study area is located in tropical lowland rainforest in the Berau district, East Kalimantan province, within a forest concession which was in the process of being FSC certified, and two external sites: one primary forest site (Sungai Wain) and one disturbed non-certified forest site (Pusrehut) (Figure 5.1). In the Berau district, four FSC-candidate sites were selected to be sampled: one primary forest site and three selectively logged forest sites logged in 2003, 2007 and 2011. One site of primary forest was selected in the Sungai Wain Protected forest and one disturbed site was selected in the Pusrehut forest, in the district of Kutai

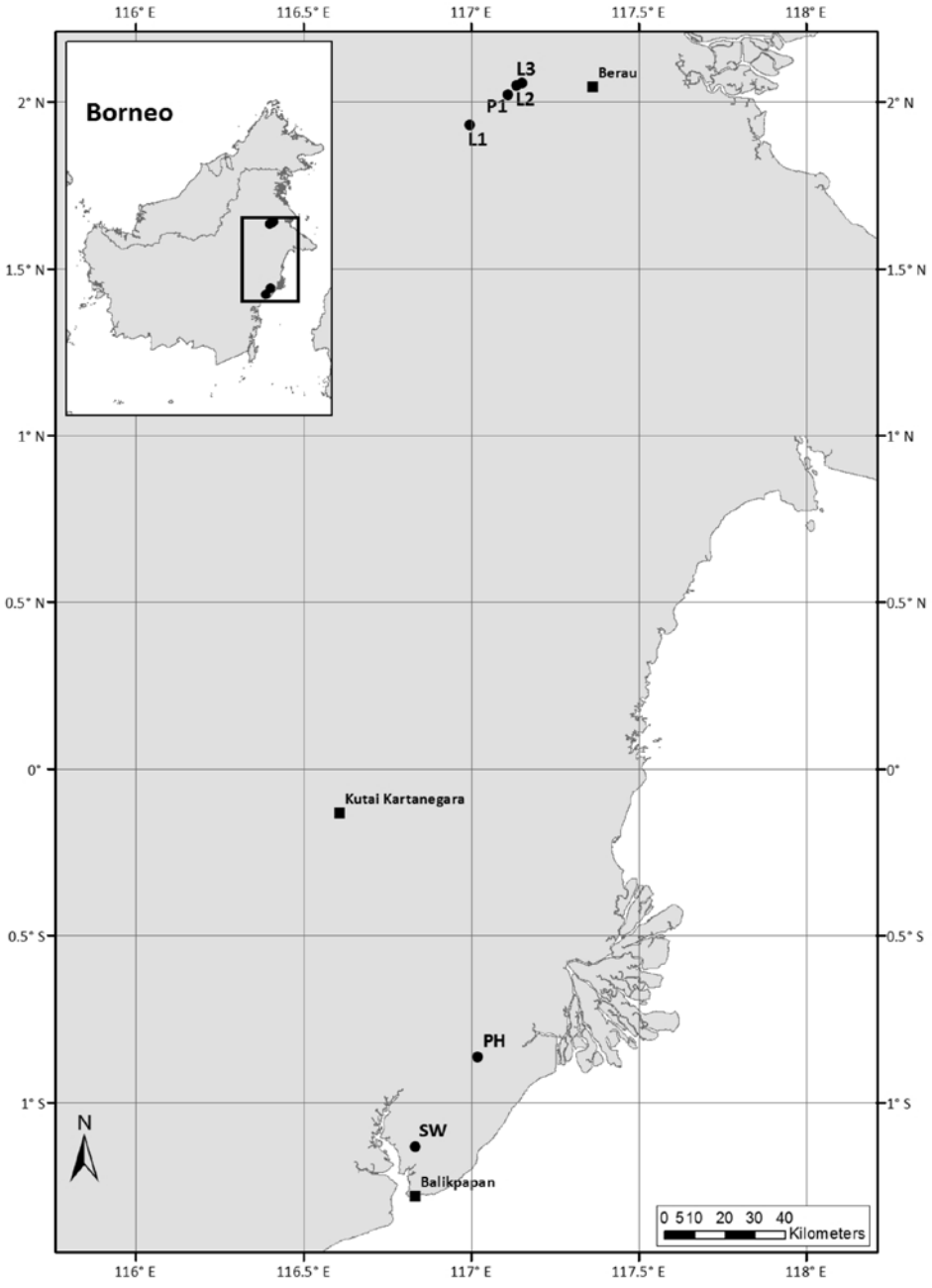

Figure 5.1
Map of East Kalimantan with the location of sampling points. P1 primary forest site, L1 logged in 2011, L2 logged in 2007, L3 logged in 2003, SW Sungai Wain forest site (primary forest), PH Pusrehut forest site (disturbed forest).

Kartanegara. This non-certified site had been logged long ago, in the 1970s, had been moderately to heavily burned in 1982/1983 and then replanted (Figure 5.1). It had been subjected to illegal logging activities in the period up to 2014. In all sites, the elevation range is between 25-140 m above sea level (Mantel *et al.*, 2002; Slik and Eichhorn, 2003). The topography of all sites consists of a rolling hilly landscape with shallow valleys and gullies.

The three forest types were adopted according to FAO (2001): 1) Primary forest is defined as a forest that has been logged more than 30 years ago or has never been logged; 2) Selectively logged forest is defined as forest with specific areas where the trees have been removed less than 30 years ago as a result of harvesting or logging, and where the forest is expected to regenerate naturally or with the aid of silvicultural measures; 3) Disturbed forest is defined as forest containing significant areas which have been exposed to human disturbance, including clearing, harvesting or logging, felling for wood extraction, hunting, anthropogenic fires and road construction.

Bird surveys

Within each of the study sites five sampling points were identified at a distance of 200 m from each other and these were used for point counts to assess bird species presence (Bibby *et al.*, 2000). Observations were done in all sites between February and August 2014. In total we conducted 30 point counts, 2 × 5 in the primary forest, 15 in forest sites logged selectively and 5 in the disturbed forest site. Point counts are generally preferred as a counting method in dense forests, because they are suggested to cause less disturbance in comparison to e.g. transect counts and offer the possibility to include auditory observations (Bibby *et al.*, 2000).

Counts were repeated four times during mornings (at dawn) and late afternoons (at dusk), each on subsequent days, based on Slik & Balen (2006) (Table 5.1). The observations were made by the 1st, 4th and 5th authors of this paper and a bird expert from the University of Mulawarman, Samarinda. Morning visits usually started around 6 am and afternoon visits around 16 pm, each visit lasting approximately 2 hours. During a site visit all 5 sampling points were surveyed for 15 min each (following Pieterse & Wielstra, 2005; Slik & Van Balen, 2006). All individual birds seen and heard were recorded. No distance limitation was used, but the bias caused by this was considered similar for all sites. We also used a digital sound recorder Olympus Linear PCM recorder LS-11 placed on a tripod, to record all the bird sounds for later identification. These recorded bird sounds were used as a reference for which we asked advice from a Dutch bird expert (Bas van

Balen) and two Indonesian bird experts (Agus Prastiono & Satriyo Susito). In addition, we used bird sounds from the xeno-canto website. In order to allow any birds that might have been scared away when approaching the sampling site to return, counts started 2 min after reaching each observation point. To minimize a possible bias occurring from visiting the sampling points at the same time of day, the points were visited in a reversed order during alternating visits. Counts were not conducted during rain fall because of the decrease in bird activity during such weather conditions (Bibby *et al.*, 2000; Slik & Balen, 2006). Throughout this study, each bird species was assigned to a single bird guild, based on Wielstra *et al.* (2011) and De Iongh *et al.* (2007).

Data Analyses and Statistics

Based on literature (Smythies, 1999; Phillipps & Phillipps, 2011), we determined whether each bird species was endemic to Borneo or not. We also determined the individual body mass (grammes) based on Thiollay (1995) and Dunning (2007) (Table 5.1). For each bird species, a data set was created which contained the following dependent variables per point count location: i) 'Total species': all species encountered during the eight visits; ii) 'Mean abundance': the average number of individuals per visit; iii) 'Mean species': the average number of species per visit (Table 5.2). The six forest sites were compared with respect to the above parameters. Our forest sites were regarded as randomly selected within the lowland rainforest areas of Kalimantan. We used either a Linear Mixed Model or a Generalized Linear Mixed Model, depending on whether the transformed data showed a Poisson distribution or not, with 'Forest' as random effect variable. The transformation that was applied included a multiplication of the data with a constant and then rounding the multiplied data.

Following Wielstra *et al.* (2011), the birds were classified according to diet in so called "guilds": Nectarivore (N), Frugivore (F), Frugivore / Insectivore (FI) and Insectivore (I). For each of these guilds we calculated the average abundance per point count over the eight visits. We also calculated the ratio of endemic bird species versus all bird species per point count, for each guild. Primary forests were compared to secondary forests with respect to 'Mean abundances per guild' and 'Mean ratio per guild' using a generalized Linear Mixed Model for which 'Forest' was included as random effect variable.

For testing, we used a Likelihood-Ratio Test (LRT) and Kruskal Wallis Test. We performed the statistical analyses using R software 3.2.2 with R Development Core Team 2015. For the mixed models, we used lmer () or the glmer () of the package lme4 (Bates 2014), version 1.1-7

Results

A total of 10 endemic avian Bornean species were recorded during field work in all sites (Table 5.1), with 9 endemic species recorded in the primary forest sites (Berau and Sungai Wain) and 8 endemic species in the secondary forest sites (Berau and Pusrehut) (Table 5.1). The Bornean Barbet (*Megalaima eximia*) was more abundant in the primary forest sites compared to the secondary forest sites (Table 5.1). The Bornean Ground-cuckoo (*Carpococcyx radiatus*) and the Bornean Blue Flycatcher (*Cyornis superbus*) were absent in the secondary forest sites. The Dusky Munia (*Lonchura fuscans*) was absent in the primary forest sites.

We found that most endemic avian Bornean species had a body mass above 41g (provide statistical proof); only 2 species had a smaller body mass (i.e. one Dusky Munia (*Lonchura fuscans*) and one Yellow-rumped Flowerpecker (*Prinochilus xanthopygius*) (Table 5.1).

When comparing the primary forest site with the secondary forest sites, we did not find significant differences in 'Total species number', 'Mean abundance', or 'Mean species number' for the endemic avian Bornean species (Figure 5.2; Table 5.2). However, we did find a significant difference between the primary forest site and secondary forest sites in the ratio between the number of endemic species and all species of the insectivorous guild per visit per site ($p = 0.041$) (Table 5.3). Also, we found a significantly higher abundance of insectivores in primary forest as opposed to secondary forest ($p = 0.011$). We found no significant differences for any of the other guilds when we compared the primary forest site with secondary forest sites (Table 5.4, Figure 5.3).

Table 5.1
Comparative occurrence of endemic avian Bornean species per day per site based on weight class, feeding guild and mean abundance in primary versus secondary forest sites.

Endemic species	Body mass (g)	Feeding guild	Primary forest		Secondary forest			
			Berau	Sungai Wain	Logged 2003 (Berau)	Logged 2007 (Berau)	Logged 2011 (Berau)	Pusrehut
Bornean Ground-cuckoo *Carpococcyx radiatus*	321–640	Arboreal frugivore/ insectivore	0	0.375	0	0	0	0
Bornean Blue Flycatcher *Cyornis superbus*	11–20	Arboreal insectivore	0	0.125	0	0	0	0
Dusky Munia *Lonchura fuscans*	<10	Terrestrial frugivore	0	0	0	0.25	0.125	0.25
Bornean Barbet *Megalaima eximia*	41–80	Terrestrial frugivore	0	3.125	0	0	0	2.25
Blue-banded Pitta *Pitta arquata*	41–80	Arboreal insectivore	0	0.25	0	0	0	0.25
Blue-headed Pitta *Pitta baudii*	41–80	Arboreal insectivore	1	0	0	0	0.125	0.125
Bornean Black Magpie *Platysmurus atterimus*	161–320	Arboreal insectivore	0.25	2	0.25	0.75	1.125	0
Bornean Peacock-pheasant *Polyplectron schleiermacheri*	641–1280	Understorey frugivore	0	0.25	0	0	0	0.25
Yellow-rumped Flowerpecker *Prinochilus xanthopygius*	<10	Arboreal nectarivore	0.25	0.125	0.5	0.25	0	0
Bornean Wren-babbler *Ptilocichla leucogrammica*	21–40	Arboreal insectivore	0.125	0	0	0.125	0.125	0

Table 5.2
The difference between primary and secondary forest sites in total species, mean abundance and mean species; * = $p < 0.05$; NS = not significant.

Location / Forest types (sites)	Point Counts	Total Endemic Species	Mean Abundance of Endemic	Mean Endemic Species
Berau				
▪ Primary forest1	1	3	0.75	0.625
	2	1	0.125	0.125
	3	0	0	0
	4	3	0.5	0.5
	5	1	0.25	0.25
SungaiWain				
▪ Primary forest2	1	4	1.75	1.5
	2	4	1.25	0.875
	3	2	0.875	0.75
	4	2	1.5	1.125
	5	4	0.875	0.75
Berau				
▪ Logged 2003	1	0	0	0
	2	1	0.25	0.125
	3	1	0.25	0.125
	4	0	0	0
	5	1	0.25	0.125
▪ Logged 2007	1	0	0	0
	2	2	0.375	0.25
	3	3	0.625	0.5
	4	1	0.25	0.25
	5	1	0.125	0.125
▪ Logged 2011	1	1	0.125	0.125
	2	2	0.5	0.375
	3	1	0.25	0.125
	4	1	0.375	0.25
	5	2	0.25	0.25
Pusrehut				
▪ Disturbed forest	1	3	1	0.75
	2	0	0	0
	3	2	0.75	0.625
	4	3	0.875	0.75
	5	2	0.5	0.375
p-values LRT-test		0.167(NS)	0.241(NS)[a]	0.154(NS)[a]

[a] Poisson distribution of the error was assumed

Table 5.3
The difference between primary and secondary forest sites in ratio of endemic avian Bornean species vs all avian species observed per feeding guild: N, F and I, per visit per site; * = p < 0.05); NS = not significant.

Location / Forest types (sites)	Point Counts	Mean ratio Nectarivores	Mean ratio Frugivores	Mean ratio Insectivores
Berau				
▪ Primary forest1	1	0.125	0	0.105
	2	0	0	0.021
	3	0	0	0
	4	0.111	0	0.083
	5	0	0	0.057
SungaiWain				
▪ Primary forest2	1	0	0.75	0.114
	2	0	0.333	0.114
	3	0	0.455	0.024
	4	0	0.5	0.067
	5	0.25	0.4	0.083
Berau				
▪ Logged 2003	1	0	0	0
	2	0	0	0.026
	3	0.67	0	0
	4	0	0	0
	5	0.25	0	0
▪ Logged 2007	1	0	0	0
	2	0.1	0.25	0
	3	0.125	0	0.073
	4	0	0	0.067
	5	0	0	0.042
▪ Logged 2011	1	0	0.125	0
	2	0	0	0.061
	3	0	0	0.028
	4	0	0	0.1
	5	0	0	0.071
Pusrehut				
▪ Disturbed forest	1	0	0.455	0.029
	2	0	0	0
	3	0	0.455	0
	4	0	0.556	0.045
	5	0	0.2	0.036
p-value		0.553 (NS)[a]	0.900(NS)[b,c]	0.041 (*)[b,c]

[a] p-value Kruskal-test

[b] p-value LRT-test

[c] Poisson distribution of the error was assumed

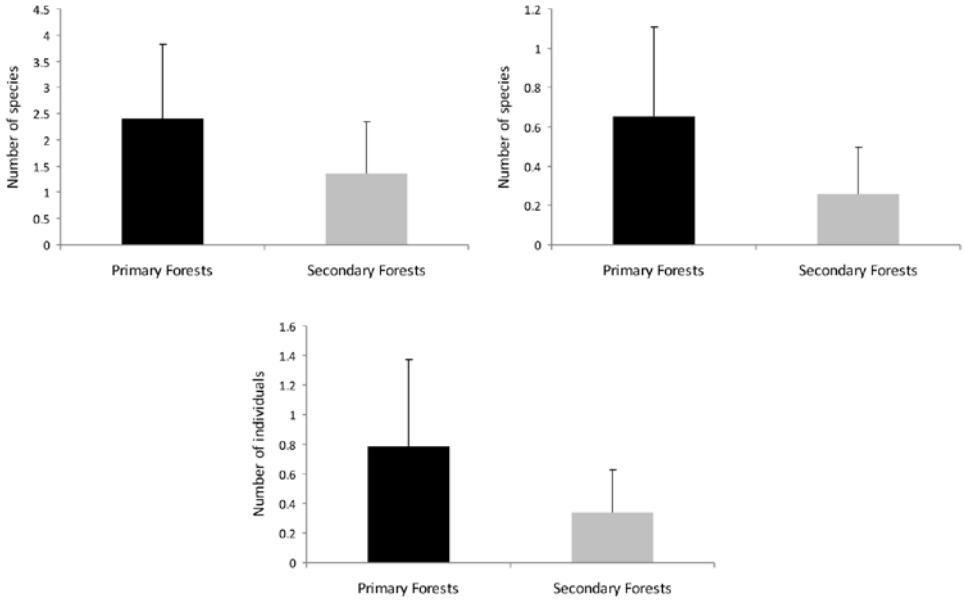

Figure 5.2
Species richness per plot (A), species richness per observation (B), abundance per observation (C) of endemic birds in the primary forest sites (black) and secondary forest sites (grey).

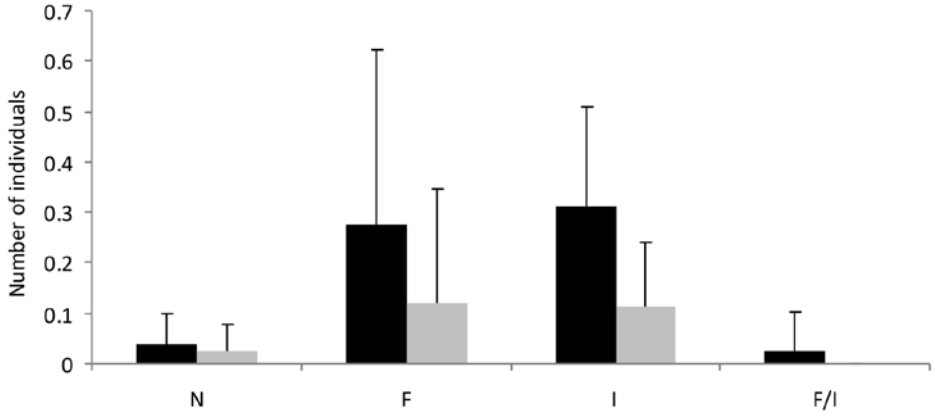

Figure 5.3
Mean abundance (plus standard deviation) endemic avian species per diet guild: Nectarivore (N), Frugivore (F), Insectivore (I), Frugivore/insectivore (F/I) in the primary forests (black) and secondary forests (grey).

Table 5.4
The difference between primary forests and secondary forests in abundance per diet guild: nectarivore, frugivore, insectivore and frugivore/insectivore birds per visit per site; * = p < 0.05); NS = not significant.

Location / Forest types (sites)	Point counts	Mean Nectarivores Endemic species	Mean Frugivores Endemic species	Mean Insectivores Endemic species
Berau				
▪ Primary forest1	1	0.125	0	0.5
	2	0	0	0.125
	3	0	0	0
	4	0.125	0	0.375
	5	0	0	0.25
SungaiWain				
▪ Primary forest2	1	0	0.75	0.5
	2	0	0.25	0.625
	3	0	0.625	0.125
	4	0	0.875	0.25
	5	0.125	0.25	0.375
Berau				
▪ Logged 2003	1	0	0	0
	2	0	0	0.125
	3	0.125	0	0
	4	0	0	0
	5	0.125	0	0
▪ Logged 2007	1	0	0	0
	2	0.125	0.125	0
	3	0.125	0	0.375
	4	0	0	0.25
	5	0	0	0.125
▪ Logged 2011	1	0	0.125	0
	2	0	0	0.375
	3	0	0	0.125
	4	0	0	0.25
	5	0	0	0.25
Pusrehut				
▪ Disturbed forest	1	0	0.625	0.125
	2	0	0	0
	3	0	0.625	0
	4	0	0.625	0.125
	5	0	0.25	0.125
p-value		0.548 (NS)[a]	0.402 (NS)[a]	0.011 (*)[b,c]

[a] p-value Kruskal-test
[b] p-value LRT-test
[c] Poisson distribution of the error was assumed

Discussion

Survival rate of endemic Bornean avian species

Eight out of ten endemic bird species observed throughout our sampling points occurred in the selectively logged sites, which is remarkable, especially in view of the reported drastic reduction in potential food trees after logging (Johns, 1987; Meijaard *et al.*, 2005). However, studies in the Philippines also found that endemic bird species may survive in forest remnants after logging (Brooks *et al.*, 2001; De Iongh & Van Weerd, 2006), and in eastern Borneo, secondary forests were found to support all avian species observed in primary forests (Wielstra *et al.*, 2011; Arbainsyah *et al.*, 2015b). Some species even appear to be unique to secondary forest habitats (Smythies, 1999; Philippe & Phillip, 2011), which is in accordance with our finding that the Dusky Munia (*Lonchura fuscans*) was observed exclusively in secondary forest sites (Table 5.1).

Since most avian species are specialized feeders, having become adapted to particular kinds of food, their abundance is determined by the availability of food sources (Meijaard *et al.*, 2005; Boer, 2006). In tropical forests, where food sources are diverse, endemic bird species are generally less dependent on a single type of food source, except for insectivorous birds, which are more specialized than other guilds and are thus more sensitive to habitat loss, caused by e.g. logging (Wong, 1985). The negative impact of logging on the terrestrial insectivorous guild reported by other authors (De Iongh & Van Weerd, 2006; De Iongh *et al.*, 2007, Mason, 1996; Pieterse & Wielstra, 2005; Slik & Balen, 2006; Arbainsyah *et al.*, 2015b) and our observation that the insectivorous guild was less abundant in logged secondary forest is in line with this and raises major concerns for the conservation of species belonging to this specialized guild.

Although tree flowering stimulation by disturbance in secondary forests (e.g. through increased sunlight due to tree canopy opening) can lead to a temporary increase in nectarivores (Ghazoul & Hellier, 2000; Lambert & Collar, 2002; Slik & Van Balen, 2006; Wielstra *et al.*, 2011), this was not evident from our findings, probably because fruit trees only occurred in limited numbers in logged sites in our study area.

In conclusion, whereas selective logging did not cause severe damage to the wider group of Bornean endemic birds in terms of their diversity, our study confirms the sensitivity of insectivorous endemic birds to the impacts of logging, which should be seriously considered for any future conservation strategy targeting this guild and its remaining habitat in Borneo.

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6

Synthesis

General discussion

Van Kuijk *et al*. (2009) suggested that there is no quantitative evidence of an impact of FSC-certified logging on biodiversity. In East Kalimantan, primary rainforests are under considerable pressure from both legal and illegal logging activities, which has led to fragmentation and degradation of the remaining tropical rainforests. Additional pressure on these forests arises from landless farmers, who practice shifting cultivation (Slik *et al*., 2002; Meijaard *et al*., 2005). The question now arises whether FSC certification standards are helping to conserve the biodiversity which is still contained within these forests or are as detrimental as conventional logging practices. To address this issue, I studied the response of plant and avian communities to logging in selectively logged forest sites as compared to primary forest sites in lowland rainforests of East Kalimantan, with a particular emphasis on plant diversity, forest structure, and avian communities.

One of the characteristics of avian communities in tropical rainforest is the high number of species classified as endemic (Anderson, 1994; Stattersfield *et al*., 1998; Boer, 2006). Since endemic avian species diversity has been demonstrated to be highly sensitive to disturbance such as logging (MacArthur and MacArthur, 1961; Henle *et al*., 2004; Meijaard *et al*., 2005), impact studies using birds could provide valuable information on the status of forest disturbance (Ghazoul & Hellier, 2000; De Iongh & Van Weerd, 2006; De Iongh & Persoon 2010).

Field research

My study was restricted to one forest concession with several logging histories in the Berau district and two external forest sites: one site in the district Balikpapan and one site in the district Kutai Kartanegara, East Kalimantan. This has resulted in a relatively small scale study in a forest concession which was in the

process of FSC certification. Because of the small scale and the fact that full FSC certification was not yet obtained in the Berau concession the conclusions of my study should be handled with care. The secondary forest sites in this concession had been selectively logged in 2003, 2007 and 2011. In addition, I selected one primary forest site in the Berau concession, one primary forest site in the Sungai Wain protected forest in Balikpapan, and one disturbed forest site in the Pusrehut forest, situated in the Kutai Kartanegara region (see Chapter 1 for more details). I realize that these sites were far apart and that the Berau sites were more similar than the other external sites. However all sites were classified as tropical Dipterocarp lowland forest and in that sense belonged to the same habitat type.

Structure, composition and diversity of plant communities

In order to obtain a complete overview of possible changes in forest structure, I sampled all trees, saplings and seedlings in all forest sites (Appendix 1 to 3). Tree densities were significantly lower in the sites logged 1 and 5 years ago, while sapling and seedling densities were not significantly different among all forests sites (Table 2.3, 2.4 and 2.5). Dicot trees accounted for a higher plant diversity in the primary forest site, while the number of species of palm trees was higher in some of the selectively logged forest sites, especially in the forest site logged 10 years ago. Regarding saplings, only treelets accounted for a higher overall plant diversity in the primary forest site, while the number of species of lianas, shrubs and herbaceous plants was higher in the selectively logged forests. Seedlings, palm lianas (rattans) accounted for a higher overall plant diversity in primary forest, while the number of species of monocots (lianas and herbs), dicots (trees, lianas and shrubs), and ferns (trees, lianas and herbs) was higher in the selectively logged forest sites. The enhanced light conditions created by the numerous gaps in the canopy most likely caused this effect; pioneer species especially tend to respond to improved light conditions by growing faster than species of later successional stages (Arbainsyah, pers. obs., Bazzaz & Pickett, 1980; Uhl & Clark, 1983; Swain & Whitmore, 1988; Vazques-Yanes & Orozco-Segovia, 1993; Slik *et al.*, 2002; Eichhorn *et al.*, 2006).

The density of small tree seedlings was highest in the primary forest site in Berau, while the density of liana seedlings was two times higher in the selectively logged forest sites (Figure 2.2). Slik *et al.* (2002) reported similar results. Densities of life forms such as herbs and shrubs were more than two times higher in the selectively logged forest sites (Figure 2.2, Table 2.5). In the selectively logged forest sites, pioneer species were dominant, probably as a result of the dramatic increase of light penetrating to the forest floor after logging. Several studies showed

that pioneer species occur only after disturbance, when the light or temperature levels are raised substantially (Bazzaz & Pickett, 1980; Uhl & Clark, 1983; Swain & Whitmore, 1988; Vazques-Yanes & Orozco-Segovia, 1993; Eichhorn *et al.*, 2006). Particularly the pioneer *Macaranga hypoleuca* was very dominant in the selectively logged forest sites. Similarly, after logging regeneration is generally better when a forest logged previously has been occupied by successional vegetation (Slik *et al.*, 2002; Meijaard *et al.*, 2005). My findings suggest that selectively logged forest could recover, provided that further destruction by landless farmers is strongly reduced. This is also confirmed by the fact that the studied forest sites had been selectively logged, and tree species diversity was found to be higher in the diversity of plants, and to have more or less the same value in the number of species although in a different growth stage (Table 2.2). Previous logging of our forest sites had not resulted in permanent deforestation.

My study further showed that overall tree densities were significantly higher in the primary forest site than in the forest sites selectively logged 1 and 5 years ago, but approximately similar to that in the forest site logged 10 years ago, which is in accordance with other scientific findings (Slik *et al.*, 2002; Sist *et al.*, 2003), suggesting that the impact of selective logging was similar for the three sites. Although the forest structure was affected in some of the selectively logged forest sites, in the forest site logged 1 and 5 years ago, species numbers were not much lower compared to the primary forest site. In addition, a comparison of vegetation in the four forests sites suggested that in terms of species composition and diversity selective low impact logging largely compensated for the strong negative impact of initial logging. Our results therefore suggest a sufficient level of tree species regeneration, as was observed at several sites in East Kalimantan (e.g. Siegert *et al.*, 2001; Slik *et al.*, 2002; Yassir *et al.*, 2010).

Plant species diversity in relation to stem diameter and plant functional types

Ten years after selective logging, vegetation succession appeared to have reached a stage which was sufficiently developed to study forest recovery based on patterns in forest structure, tree species composition, and tree species diversity in relation to stem diameter and Plant Functional Type. So far, there are few scientific studies reporting on these parameters after logging. Van Kuijk *et al.* (2009) suggested that there is no quantitative evidence of an impact of FSC-certified logging on biodiversity in tropical forests. The intact vegetation structure and the absence of removed tree stems were most pronounced in the primary forest site, whereas in forest sites logged 1 and 5 years ago the number of tree stems was

lower than in the primary forest site (Table 3.1). In addition, my study showed significant differences between the abundance of tree stems in the small diameter class and in tree species richness in the selectively logged forest sites compared to the primary forest site, with higher tree species diversity in the primary forest site (Table 3.2 and 3.3).

The plant functional types (PFT) of the four forest sites (primary forest, forest logged selectively 1, 5 and 10 years ago) were studied by calculating tree numbers as the sum of trees counted in the three PFT classes (light, medium and heavy hardwood: see Chapter 3 for further details). These three classes reflected a high degree of contrasting ecological plant functional types; i.e. most abundant species were often referred to the classes of "light and medium hardwood", while few species were classified as "heavy hardwood" (Table 3.5). A comparison of the primary forest site and the selectively logged forest sites regarding the PFT showed that the abundant tree stems were largely dominated by pioneer species, while the PFT of tree stems were dominated by light wood (Figure 3.2, Table 3.5). Tree stem densities and tree species abundance of the "heavy hardwood" PFT were significantly lower in forest sites selectively logged 1 and 5 years ago compared to the primary forest site, while tree stem densities in the "light hardwood" PFT and tree species abundance were higher in forest sites logged selectively compared to the primary forest site (Figure 3.2, Table 3.5). This is partly the result of large differences in the classification of PFT among the selectively logged forest sites and the primary forest site. Secondary succession has also been described in terms of replacement of tree stems of different tree density classes (Brown & Lugo, 1990; Verburg & Van Eijk-Bos, 2003).

In the selectively logged forest sites, the species *Shorea parvifolia,* appeared to be one of the few Dipterocarp timber trees which were still present 10 years after selective logging (Table 3.4), thus being able to endure logging pressure and surviving during post logging succession. While many other species were reduced in density by logging, *Shorea parvifolia* is likely to further recover in the selectively logged forest sites. Further regeneration of the PFT classes depends on the available stock of small stems of seedlings and saplings in the selectively logged forest sites (Arbainsyah *et al*., 2014).

My results show that selective logging mainly affects the smallest tree stems up to 30 cm dbh of the forest understorey and mid-levelstorey as well as the class with stems between 70 and 80 cm of the emergent trees in the upperstorey, due to the negative relation between tree stem diameter and plant functional types. In the selectively logged forest sites, this PFT-related pattern might also result in selective extinction of certain tree species/genera because of differences in

the tree species composition among PFT classes between the primary forest site and secondary forest sites. It is therefore likely that, although tropical rainforests could recover from selective logging to some extent through the process of succession, their species composition will change considerably for a long time after logging. Evidence from my research suggests that it could take at least 10 years for forests to recover from heavy/intermediate logging to primary forest. This finding is confirmed by other authors who reported on tree species composition in tropical rainforest (e.g. Slik *et al.*, 2002; Verburg & Van Eijk-Bos, 2003).

Response of avian communities

Chapter 4 discusses the impact of selective logging on bird communities in secondary forest sites as opposed to a primary forest site. I analyzed the response to logging in terms of species richness, bird abundance and bird diversity (Shannon and Evenness indices) (Jost, 2006). I used point counts to assess bird species presence (Bibby *et al.*, 2000). In total I established 30 point counts, 2 × 5 in the primary forest, 15 in forest sites logged selectively and 5 in the disturbed forest site (for further details see Table 4.1) and for comparison of bird abundance in total 5 point counts during 8 visits in all sites (see Appendix 4). My aim was to test if I could find quantitative evidence of any impact from the FSC certification process on plant and on avian communities and to compare my results to Van Kuijk *et al.* (2009), who did not find any evidence for this. My study shows a significant difference in the mean abundance of birds observed per visit per site between two groups of forest plots: the primary forest sites had a higher number of individual birds than the secondary forest sites (Table 4.2, Figure 4.2). This difference in abundance is probably related to the fact that the primary forest sites provide more food resources than the non-primary forest sites (Slik & Van Balen, 2006).

The mean abundance of both the terrestrial avian guild and the arboreal guild was significantly higher in the primary forest sites compared to the secondary forest sites (Table 4.3). At the feeding guild level, I found a higher abundance of frugivores/insectivores in the primary forests compared to the secondary forests (Table 4.4, Figure 4.5). Although this finding differs from other studies (e.g. Johns, 1996; Van Hoeven *et al.*, 2000; Pieterse & Wielstra, 2005; Wielstra *et al.*, 2011), it could be an indication of a positive impact of the FSC certification process on bird species diversity

The suggestion that a reduction of the understorey layer could strongly reduce the availability of food sources for certain birds (Karr & Brawn, 1990; Mason,

1996; Pieterse & Wielstra, 2005; Slik & Van Balen, 2006) was supported by my finding that the composition of the frugivorous / insectivorous guild differed between primary and secondary forest sites. Comparisons of both forest types with respect to bird diversity expressed as species richness or as diversity indices (the Shannon index and Evenness index), did not provide any significant differences however, indicating that the impact of selective logging on bird communities was relatively low, as was also suggested by Johns (1996), Van Hoeven *et al.* (2000) and Wielstra *et al.* (2011) in their studies of Bornean bird communities.

Endemic avian Bornean species

The ratio between endemics and all species appeared to be significantly different for the insectivorous guild (Table 5.3). I also found a significantly higher abundance of insectivores in the primary forest sites as compared to the secondary forest sites. The Bornean Ground-cuckoo (*Carpococcyx radiatus*) and Bornean Blue Flycatcher (*Cyornis superbus*) were especially abundant in the primary forest sites. Both species were absent in the secondary forest sites (Table 5.1).

The higher abundance of the insectivorous guild in the primary forest site compared to the secondary forest sites which I found was confirmed by previous studies which demonstrated a negative impact of logging on the insectivorous guild (Mason, 1996; Pieterse & Wielstra, 2005; Slik & Balen, 2006; Arbainsyah *et al.*, 2015). Species richness of endemic avian Bornean species, however, was not affected by logging, indicating a rather low level of disturbance by selective logging.

Conclusions

The following conclusions can be drawn from this study:

What are the differences in vegetation structure and composition in selectively logged forest sites in comparison to primary forest? (Chapter 2)

1 As predicted, the sapling vegetation disclosed a high diversity in the selectively logged forest which was in the process of FSC certification, represented by the newly regenerated species *Madhuca malaccensis*. Stems were two times more abundant in the selectively logged forest sites than other species in the forest site logged 5 years ago compared to the primary forest site.
2 As ingrowth of seedling vegetation represented by some new pioneer species in the selectively logged forest sites, newly recorded plants, such as *Maca-*

ranga hypoleuca, as it was fast-growing and particularly abundant in the selectively logged forest sites compared to primary forest. I therefore conclude that seedling vegetation will support the species richness regeneration in the selectively logged forests of my study.

What are the differences in plant species diversity by diameter class and plant functional type between selectively logged forest sites in comparison to primary forest? (Chapter 3)

1. Selective logging mainly affected the smallest tree stems up to 30 cm dbh of the forest understorey and mid-levelstorey, and trees with stems between 70 and 80 cm dbh of the emergent trees in the upperstorey, with a clear negative relation between tree stem diameter and plant functional types.
2. Due to the relation between tree stem diameter and plant functional type classes, in the heavy hardwood class tree stem and species richness were more affected in the selectively logged forest sites under process of FSC certification (1 and 5 years ago) compared to the primary forest site. This is partly the result of large differences in the classification of PFT among selectively logged forest sites.
3. The species of *Shorea parvifolia* which is one of the main Dipterocarp timber trees was still present 10 years after selective logging under the process of FSC certification. This species contributed for 15.3% to the tree stem abundance in the light wood plant functional type, with a significantly higher tree stem density in the forest sites selectively logged 1 year ago as compared to the primary forest site. This species is one of the main Dipterocarp timber trees that may have been a target species for logging in the past.

What are the differences in avian community composition and species abundance between selectively logged forest sites in comparison to primary forests? (Chapter 4)

1. As species richness and mean abundance of birds were not affected by selective logging, I conclude that selective logging will not change species richness and mean abundance of birds in the Berau concession of my study.
2. The higher abundance of birds of the terrestrial guild in some foraging layers of the primary forest site as compared to the secondary forest site in my study, suggests a negative impact of selective logging and disturbances on the forest upperstorey.
3. As predicted, the abundance of frugivorous / insectivorous birds was significantly lower in the secondary forest sites compared to the primary forest sites. I therefore conclude that primary forest in the Berau concession more effectively supports the existing bird populations compared to forests that are selectively or non-selectively logged.

What are the differences in endemic avian species diversity and abundance between selectively logged forest sites in comparison to primary forests? (Chapter 5)
I found that the endemic insectivorous birds were more abundant in primary forest sites as compared to secondary forest sites, which confirms earlier findings on the impact of logging on avian endemic communities in East Kalimantan.

What indicators could be identified for monitoring purposes?
The process of FSC certification coincides with similar bird species diversity, but lower tree species diversity in secondary forest sites.

Does the process of FSC certification contribute to biodiversity conservation?
The set up of my research does not allow to draw hard conclusion on the impact of the process of FSC certification. However, in terms of plant species and bird species diversity there are no large differences between the Berau concession with different logging histories and the two external sites (Sungai Wain and Pusrehut).

Perspectives for future research

My research showed that most of the original plant and bird species richness had been conserved after selective logging in secondary forests, suggesting logging under a process of FSC certification had no detrimental effects, at least not on most of the species and guilds I studied. Based on this, I could recommend the currently proposed FSC (and LEI) logging strategies as effective SFM. Although some conclusions may be applicable only to the situation in East Kalimantan, they provide a valuable basis for the establishment of indicator-based strategies for biodiversity conservation. Such indicators could include a) Plant abundance; b) Sapling lianas abundance and species richness; c) Fern herb species richness; d) Avian abundance and d) Avian frugivores/insectivores. Studies on other taxa, such as butterflies or mammals as possible indicators of biodiversity loss and these could further enhance our understanding of the impacts of logging practices on tropical rainforests. (Ghazoul & Hellier, 2000; Landers *et al.*, 2004; Azevedo-Ramos *et al.*, 2002; Sheil *et al.*, 2004). Building on my findings, future studies could further elaborate on the underlying processes explaining changes in plant and bird diversity in response to forest disturbances, to formulate recommendations for sustainable forest exploitation. An interesting example of such a study would be one covering the relationships between plant diversity and bird diversity and their response to logging. Van Kuijk *et al.* (2009) concluded that there is no quantitative evidence that FSC-certified logging has an impact on biodiver-

sity conservation. My study detected a relationship between plant diversity and bird diversity.

Another important question which should be further exploited in future studies, is how plant and bird diversity relates to certain patterns in forest recovery and succession. Such studies could provide valuable comparative data, especially when methods are similar to the ones used in my study. To further enhance results acquired from such studies I would however advise to increase the sampling area targeted. My research showed the impact of logging 10 years after logging. At that time, plant diversity was still high in the selectively logged forests, although the forest structure was affected in some of the selectively logged forest sites, especially in the forest site logged 1 and 10 years ago (see Chapter 2 and 3). Bird abundance was higher in the primary forests, although I found a few differences in the feeding guilds composition between primary forests and secondary forests, which confirms earlier findings on the impact of logging on avian endemic communities (see Chapter 3 and 4). My results revealed that secondary forest sites could recover considerably when they were left undisturbed for a period of 10 years, although some species became less abundant during this time span. Recovery time spans longer than ten years may reveal to what extent selective logging leads to long term extinctions, but also how long it would take to reach a stable state of succession and if changes in plant and bird diversity are related to changes in the biodiversity. Ideally, future research should aim to integrate multiple aspects of biodiversity and ecological processes.

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Summary

The impact of Sustainable Forest Management on plant and bird diversity in East Kalimantan, Indonesia

Keywords: Sustainable forest management, Selective logging, Species richness, Forest structure, Forest recovery, Tropical rain forest.

The increasing destruction of tropical rainforests is a result of rapid changes in land use and increased logging. Evidence suggests that logging could have a substantial impact on the biodiversity of tropical rainforests. Especially illegal logging leads to multiple processes which negatively affect populations of plants and animals. FSC certification of forest concessions aims to reduce the negative impact of logging. The question is however whether FSC certification of selectively logged forest really has a positive impact on the conservation of biodiversity in the long term. So far, no quantitative evidence is available to prove this (Van Kuijk *et al.*, 2009). I examined the impact of logging under different logging regimes in East Kalimantan, by comparing forest sites which had been selectively logged 1, 5 and 10 years ago and one disturbed forest site (Pusrehut) with a site in undisturbed primary lowland rainforest. Particular emphasis was placed on plant diversity, structure of forests and bird communities. The study area is geographically diverse, consisting of rolling hilly landscape with shallow valleys and gullies. The altitude of the lowland Dipterocarp forest and sub-montane forest, ranges from 25-140 m above sea level. This provides for diverse habitats, which are rich in plant and bird communities.

Fieldwork was carried out in three forest reserves in East Kalimantan. The sites in Berau were in the process of being FSC certified. All forest sites were studied using the same methodology: 1). All terrestrial plants were sampled and identified in primary forest (1 site) and selectively logged forest (3 sites) in 600 subplots (10 × 10 m). Trees were systematically recorded along line transects of 6 ha. Saplings were recorded in 60 subplots (5 × 5 m) of 1.5 ha and seedlings were recorded in 60 subplots (2 × 2 m) of 0.24 ha, positioned alternately to the left and right of the transect centre lines at intervals of 100 m; 2). All birds were identified during point counts in all sites, in the selective logging concession in a primary site and in selectively logged forest sites in the Berau district, a primary site in Sungai Wain and a disturbed site in Pusrehut Kutai Kartanegara between February and August 2014. In all sites we selected 30 sampling points to conduct point counts at a distance of 200 m from each other were selected.

At least 156 tree species were identified during field work; the number of tree species in the forest site selectively logged 1 year ago was higher than in the other sites. Tree densities were significantly lower in the forest sites selectively logged 1 and 5 years ago compared to the primary forest site, but tree densities in the forest site logged 10 years ago were similar to those of the primary forest site. The number of tree stems was almost as high in the primary forest site compared to the selectively logged forest sites, with a total number 612 tree stems encountered. Dipterocarpaceae was the most dominant family. Some of the plant species identified were unique to either disturbed or selectively logged forest, or to primary forest, while some were found in both selectively logged forest sites and in the primary forest site. Some of the typical palm tree species, such as *Oncosperma horidum* were very abundant in the forest sites selectively logged 1 and 10 years ago, while less abundant in the other sites.

The sapling vegetation revealed a high diversity in the selectively logged forest sites compared to the primary forest site in Berau. The sites in Berau, which were in the process of being FSC certified, were over-represented by new regenerating species such as *Madhuca malaccensis,* which were more dominant than other species in the forest site selectively logged 5 years ago as compared to the primary forest site. A total of 97 plant species have been identified, with the highest number of plant species in the primary forest site. Many seedlings comprised of new pioneer species, and newly recorded plants, such as *Macaranga hypoleuca*, which is fast growing and particularly abundant in the selectively logged forest sites. The highest number of species was found in the forest site selectively logged 1 year ago, with a total number of 95 species encountered. The species richness of Dipterocarpaceae within the selectively logged forest suggests that logging in the past have had little effect on its diversity. This was especially the case for *Shorea spp*. which occurs both in primary forest and logged forest.

Many of the plant species are important for ecosystem services, which was measured by Plant Functional Types (PFT), which is representative of certain patterns in forest structure, and through tree species composition and species diversity in relation to stem diameter. Species specific wood density was used to assign species to three classes of PFT (light, medium, heavy hardwood). My research showed large differences among the PFT classes in the selectively logged forest sites. The "heavy hardwood" class, represented by a certain abundance of stems and species richness, was significantly lower in the forest sites selectively logged 1 and 5 years ago compared to the primary forest site. Stems with a higher abundance in the selectively logged forest sites generally belonged to the "light wood" class. The most abundant species in this class was *Shorea parvifolia*, which is one of the main Dipterocarp timber trees.

The study area provides suitable habitat for most of Borneo's lowland bird families. Bird observations were done in all study sites from February to August 2014. A total of 154 species were identified, including 10 endemic Bornean species.

The structure of a bird community could provide an indicator of habitat disturbance, e.g. after selective logging. Apart from the 154 bird species which were indentified in all forest sites, most species identified in the primary forest sites were also found in the disturbed and/or selectively logged forest sites. Although there were no significant differences in species composition between the six forest sites, I did find a significant higher abundance of birds per foraging layer of both the terrestrial guild and the frugivorous/insectivorous guild in primary forest sites as compared to the secondary forest sites. I also found that endemic insectivorous birds showed a significantly higher abundance in the primary forest sites compared to the secondary forest sites. This confirms earlier findings on the impact of logging on avian communities in East Kalimantan.

Diversity index data, used as an indicator for all growth stages (trees, saplings and seedlings) of the forest community, showed that all sites were floristically very diverse. This indicates that in the selectively logged forest sites the abundance of tree species was affected rather than species richness itself. This effect is even stronger in relation to diameter-related patterns of tree survival, as was confirmed by the clear pattern of tree survival related to Plant Functional Type (PFT) classes I found. In the selectively logged forest sites, this PFT related pattern might also result in selective extinction of certain tree species/genera because of differences in tree species composition among PFT classes. This means that, although large areas of the forest concession have been logged in the past, this has probably had a limited impact on the plant species richness. Bird diversity appeared to be similar in the two external sites [one primary forest site (Sungai Protected forest site) and one disturbed forest site (Pusrehut forest site)], as compared to the primary forest site and the selectively logged forest sites in Berau. However, I found a higher mean species number in the primary forest sites, which may be the result of a higher mean species abundance in the primary forest sites.

My main conclusion is that, although selectively logged forest sites were still high in tree species richness, tree densities are affected by selective logging. In the long run, selective logging will affect the presence or absence of tree species and/or genera because different tree species fulfil different functional types.

My main conclusion regarding bird communities is that selective logging affects the abundance of birds within their communities, especially in small forest sites. The risk of local species extinction is likely to increase when sites are smaller and

more isolated from undisturbed forest. Nonetheless, even the use of sufficiently large sites may not prevent certain species from becoming extinct, when logging is not selective or when selective logging continues without releasing the pressure after a certain amount of time.

Samenvatting

De impact van duurzame bos beheer (SFM) op de diversiteit van planten en vogels in Oost Kalimantan, Indonesië.

Kernwoorden: Duurzaam bos beheer, selectieve houtkap, soorten rijkdom, bos structuur, bos herstel, tropische regenwoud.

De toenemende vernietiging van het tropisch regenwoud is een resultaat van snelle veranderingen in landgebruik en toegenomen houtkap. Verscheidende onderzoeken leggen een verband tussen de toename van de houtkap en de afname van biodiversiteit in tropische regenwouden. De gevolgen van illegale houtkap zijn niet alleen zichtbaar op houtplantages, maar strekken zich uit tot in nationale parken en onderzoeksgebieden. Het doel van FSC certificatie bij de kapvergunning is het verminderen van de schade door houtkap in de bos percelen. De vraag is echter of de selectieve houtkap bij FSC certificatie inderdaad een positief effect heeft op de bescherming en het in stand houden van de biodiversiteit. Tot nu toe is er geen kwantitatief bewijs gevonden om dit te ondersteunen. Daarom richt ik mijn onderzoek op de invloed en herstel van selectieve houtkap in vergelijking met onaangetast tropisch laagland regenwoud in Oost-Kalimantan. Voor selectief gekapt regenwoud wordt gekeken naar 1,5 en 10 jaar geleden gekapte gebieden en een niet-selectief gekapt bos perceel in de Pusherut lokatie. Dit onderzoek richt zich vooral op plant diversiteit, de structuur van het bos en de diversiteit van vogel gemeenschappen. Mijn onderzoeksgebied is divers in de geologische samenstelling, het bestaat uit een glooiend landschap met nauwe valleien en ravijnen. Dit laagland en hoogland Dipterocarp bos ligt op een hoogte van 25 tot 140 meter boven zeeniveau. Door deze verscheidenheid aan landschappen is er een grote variatie in planten en dieren.

Het veldwerk werd uitgevoerd in drie bosreservaten in Oost-Kalimantan. De sites in Berau zijn in een proces van FSC-certificatie, met een primaire site en selectief gekapte bosgebieden. Deze bosgebieden werden bestudeerd met behulp van dezelfde methode: 1) alle landplanten werden bemonsterd en geïndentificeerd in primair bos (1 site) en selectief gekapt bos (3 sites) in 600 subplots (10 × 10m). Bomen werden systematisch geïndentificeerd langs lijn transecten van 6 ha. Jonge boomscheuten werden geregistreerd in 60 subplots (5 × 5m) van 1,5 ha. en zaailingen werden geregistreerd in 60 subplots (2 × 2m) van 0,24 ha. afwisselend gepositioneerd aan de linker en rechterkant van de transecten met een interval van 100 m; 2) Alle vogels werden geobserveerd tijdens punt tellingen in alle sites, in de selectieve houtkap concessie, een primair bos en 3 selectief gekapte bossen

in het Berau district, een primair bos in Sungai Wain en een niet-selectief gekapt bos in Pusrehut Kutai Kartanegara in de periode van februari tot augustus 2014. De vogelpopulatie werd vastgesteld door 30 punt tellingen op een afstand van 200 m van elkaar in alle locaties.

Ten minste 156 boomsoorten werden tijdens het veldwerk geïdentificeerd. In het 1 jaar geleden selectief gekapte bosgebied was het aantal boomsoorten het hoogste in vergelijking met andere sites. De dichtheden van bomen waren significant lager in de 1 en 5 jaar geleden selectieve kap boslocaties in vergelijking met de primaire bosgebieden, maar boom dichtheden in de 10 jaar geleden boskaplocaties waren vergelijkbaar met die van het primaire bos. Het aantal boomstammen was bijna even hoog in primair bos vergeleken met de selectief gekapte bosgebieden, in totaal werden 612 boomstammen aangetroffen, Dipterocarpaceae was de meest dominante familie. Verscheidene geïdentificeerde planten soorten zijn karakteristiek voor verstoord, gekapt en primair bos en soorten werden waargenomen in selectief gekapte sites en primair bos. Somige palm soorten, zoals *Oncosperma horidum* kwamen zeer veel voor in de 1, en 10 jaar geleden gekapte bossen en in mindere mate in de andere gebieden.

Uit de vegetatie studie naar jonge boomscheuten bleken de selectief gekapte bossen een grotere diversiteit te vertegenwoordigen vergeleken met de andere onderzoeksgebieden. In het Berau onderzoeksgebied waren snel groeiende soorten, zoals *Madhuca malaccensis*, dominanter aanwezig in 5 jaar herstellend bosgebied vergeleken met primair bos. Gedurende het onderzoek zijn er in totaal 97 planten soorten geïdentificeerd, waarvan de meeste in het primair bos werden gevonden. Veel zaailingen waren vertegenwoordigd door nieuwe pionier soorten, zoals *Macaranga hypoleuca*, dat is een snel groeiende soort en was deze bijzonder overvloedig in de selectief gekapte bosgebieden. Het hoogste aantal soorten werd gevonden in het 1 jaar geleden selectief gekapte bosgebied, waar in totaal 95 soorten werden aangetroffen. Uit de soortenrijkdom van Dipterocarpaceae binnen het selectief gekapt bos blijkt dat de houtkap in het verleden weinig effect had op de diversiteit. Dit was vooral het geval voor *Shorea* spp. Deze soort kan, zowel in het primair bos als in verstoord bos groeien.

Veel van de plantensoorten zijn belangrijk voor ecosysteemdiensten, deze invloed kan worden uitgedrukt in Plant Functional Types (PFT) klassen. Deze wordt opgesteld door het registreren van patronen in bos structuur, de soorten samenstelling, en soortendiversiteit in relatie tot een diameter van de stam. Soortspecifieke hout dichtheid werd gebruikt om soorten toe te wijzen aan drie klassen van PFT (licht, gemiddeld, en zwaar hardhout). Mijn onderzoek toonde grote verschillen aan tussen de PFT klassen in de selectief gekapte bosgebieden.

De “zware hardhout” klassen, vertegenwoordigd door de hoeveelheid van stammen en de soortenrijkdom, was significant lager in 1 en 5 jaar geleden selectief gekapte gebieden in vergelijking met primair bos. Lichte hout klassen werden juist oververtegenwoordigd in selectief gekapte bosgebieden. Van deze groep, is *Shorea parvifolia* een veel voorkomende soort en deze is een van de belangrijkste Dipterocarp houtkap soorten

Mijn studie gebied is een habitat voor het grootste deel van de laagland vogel families in Borneo. Alle observaties werden gedaan tussen februari en augustus 2014. In totaal werden 154 vogelsoorten geidentificeerd, waarvan 10 soorten die tot de Borneose endemische soorten behoren.

De veranderingen in structuur van de vogel gemeenschap kunnen worden gezien als een reactie op de veranderingen in habitatstructuur van het verstoorde bos na selectieve boskap. Er zijn verschillen gevonden in functionele groepen vogels tussen de primaire bossen en de secundaire bossen. In het primair bos zijn naast de soorten die alleen in onverstoord gebied voorkomen ook veel soorten gevonden die ook voorkomen in verstoord gebied. Er zijn geen significante verschillen gevonden in de soorten diversiteit tussen de 6 onderzoeksgebieden. De samenstelling van de vogelsoorten wordt ook beïnvloed door de aantallen per soort. In het algemeen, vond ik een significant hogere abundantie aan vogels die op de grond foerageren in primair bos ten opzichte van het secundair bos. Ik vond ook significante verschillen in de abundantie van de fruit-/insecteneters tussen de primaire bosgebieden en het secundair bos. Afgezien van het verschil in de abundantie van de genoemde vogel gilde, onderzocht ik ook de aanwezigheid van inheemse vogelsoorten. Eén van de kenmerken van de vogel gemeenschappen in tropische gebieden is het grote aantal endemische soorten. Hierbij vond ik dat ook de functionele groep van endemische insecteneters een significant hogere abundantie vertoonde in het primair bos ten opzichte van het secundair bos. Dit bevestigt eerdere bevindingen over de gevolgen van houtkap op aviaire gemeenschappen in Oost-Kalimantan.

De diversiteitsindex wordt gebruikt als een indicator voor de samenstelling van het bos, en is gebaseerd op de verhoudingen van groei stadia (bomen, scheuten en zaailingen). Uit deze diversiteitsindex bleek dat alle sites nog zeer divers zijn. Dit is een indicatie dat in het selectief gekapt bos de aantallen soorten sterker zijn afgenomen dan de soorten rijkdom. Dit effect is nog sterker te zien in relatie tot de diameter en het overleving van de bomen. In de selectief gekapte bossen, kan dit PFT gerelateerd patroon ook leiden tot het selectieve uitsterven van bepaalde boomsoorten/geslachten als gevolg van verschillen in de samenstelling van boomsoorten onder PFT klassen. Dit betekent dat, hoewel grote delen van een

concessie bosgebied zijn gekapt in het verleden, dit waarschijnlijk een beperkte invloed heeft op de diversiteit en de samenstelling van plantensoorten. Een andere bevinding van mijn studie, is dat de vogel diversiteit zeer vergelijkbaar was tussen de twee externe sites [één primaire bosgebied (Sungai beschermde bosgebied) en een verstoorde bosgebied (Pusrehut bosgebied)], met die uit het primaire bos en de selectief gekapte bosgebieden in Berau. Ik vond wel een hogere abundantie van vogels in de primaire bosgebieden vergeleken met de selectief gekapte bosgebieden. Dit is waarschijnlijk het gevolg van een hoger gemiddelde aantal individuen per soort in de primaire bosgebieden. Ik vond ook significante verschillen in de abundantie van de fruit-/insectenetende gilde, de insectenetende gilde en van de endemische soorten tussen primaire bosgebieden en secundair bos.

Mijn belangrijkste conclusie ten aanzien van de impact van selectieve houtkap op de plantendiversiteit is dat selectief gekapte bossen wel een hoge soortenrijkdom aan bomen kunnen hebben, maar dat het aantal bomen wordt aangetast. Op den duur zal de selectieve houtkap leiden tot een veranderde samenstelling (aanwezig/afwezig) van boom soorten en/of genera omdat deze taxa andere functies gaan vervullen binnen hetzelfde bos.

Over het effect van selectieve houtkap in kleine "bosgebieden" wordt geconcludeerd dat dit de abundantie van vogels beïnvloed. Hoe kleiner de "bosgebieden" hoe hoger de kans op het lokale uitsterven van vogelsoorten. Maar een groot bosgebied waar selectieve houtkap plaatsvind geeft geen zekerheid dat er geen vogelsoorten uitsterven.

Appendix 1

List of all tree species recorded in the 10 × 10 m subplot. After each family, genus and species name respectively plant type, observed number of stems (N) and number of subplots having at least on stem exceeding 1.3 m in high of this species (S) per forest disturbance type (0 = primary forest, 1 = secondary forest, 1 year after logged, 2 = 5 years after logged, 3 = 10 years after logged.

Family	Genus	Species	Plant type	N0	N1	N2	N3	S0	S1	S2	S3
Actinidiaceae	*Saurauia*	sp.1	dicot tree	0	1	0	0	0	1	0	0
Alangiaceae	*Alangium*	javanicum	dicot tree	0	3	0	0	0	3	0	0
Anacardiaceae	*Buchanania*	sessifolia	dicot tree	2	3	2	3	2	3	2	3
Anacardiaceae	*Dracontomelon*	dao	dicot tree	0	1	1	0	0	1	1	0
Anacardiaceae	*Drimycarpus*	luridus	dicot tree	1	3	0	0	1	3	0	0
Anacardiaceae	*Gluta*	macrocarpa	dicot tree	0	0	1	0	0	0	1	0
Anacardiaceae	*Gluta*	renghas	dicot tree	0	0	8	11	0	0	8	10
Anacardiaceae	*Gluta*	wallichii	dicot tree	0	0	1	0	0	0	1	0
Anacardiaceae	*Koordersiodendron*	pinnatum	dicot tree	0	2	0	0	0	2	0	0
Anacardiaceae	*Mangifera*	macrocarpa	dicot tree	0	0	0	1	0	0	0	1
Anacardiaceae	*Mangifera*	pajang	dicot tree	1	0	0	0	1	0	0	0
Anacardiaceae	*Semecarpus*	glaucous	dicot tree	0	1	0	0	0	1	0	0
Annonaceae	*Cyathocalyx*	sumatrana	dicot tree	0	1	0	0	0	1	0	0
Annonaceae	*Enicosanthum*	paradoxum	dicot tree	1	1	0	0	1	1	0	0
Annonaceae	*Mezzettia*	parviflora	dicot tree	2	1	1	4	1	1	1	4
Annonaceae	*Polyalthia*	cauliflora	dicot tree	2	6	0	0	2	4	0	0
Annonaceae	*Polyalthia*	glauca	dicot tree	2	1	0	0	2	1	0	0
Annonaceae	*Polyalthia*	lateriflora	dicot tree	1	0	0	0	1	0	0	0
Annonaceae	*Polyalthia*	rumphii	dicot tree	0	3	2	1	0	3	2	1
Annonaceae	Polyalthia	sumatrana	dicot tree	2	0	0	0	2	0	0	0
Annonaceae	Popowia	hirta	dicot tree	0	1	0	0	0	1	0	0
Annonaceae	Popowia	pisocarpa	dicot tree	0	0	1	0	0	0	1	0
Annonaceae	Sageraea	lanceolata	dicot tree	1	0	0	1	1	0	0	1
Annonaceae	Xylopia	ferruginea	dicot tree	1	4	6	4	1	4	6	4
Apocynaceae	Alstonia	angustifolia	dicot tree	0	0	2	1	0	0	2	1
Apocynaceae	Alstonia	iwahigensis	dicot tree	1	0	1	0	1	0	1	0
Bignoniaceae	Radermachera	pinnata	dicot tree	0	0	0	2	0	0	0	2
Burseraceae	Canarium	denticulatum	dicot tree	5	0	5	9	5	0	4	8
Burseraceae	Canarium	littorale	dicot tree	6	1	5	5	5	1	5	5
Burseraceae	Canarium	megalanthum	dicot tree	9	7	1	0	8	6	1	0
Burseraceae	Dacryodes	rostrata	dicot tree	6	5	2	0	6	5	2	0
Burseraceae	Dacryodes	*rugosa*	dicot tree	7	1	4	2	7	1	4	2
Burseraceae	Santiria	*apiculata*	dicot tree	0	2	0	0	0	2	0	0
Burseraceae	Santiria	*griffithii*	dicot tree	0	2	5	7	0	2	5	6

Family	Genus	Species	Plant type	N0	N1	N2	N3	S0	S1	S2	S3
Caesalpiniaceae	Cynometra	*elmeri*	dicot tree	16	1	0	0	14	1	0	0
Caesalpiniaceae	Dialium	*indum*	dicot tree	6	3	3	5	6	3	3	5
Caesalpiniaceae	Dialium	*platysepalum*	dicot tree	0	0	1	0	0	0	1	0
Caesalpiniaceae	Koompassia	*excelsa*	dicot tree	0	1	0	0	0	1	0	0
Caesalpiniaceae	Koompassia	*malaccensis*	dicot tree	2	1	7	8	2	1	7	8
Caesalpiniaceae	Saraca	*declinata*	dicot tree	9	3	0	0	8	2	0	0
Caesalpiniaceae	Sindora	*leiocarpa*	dicot tree	0	4	1	0	0	4	1	0
Caesalpiniaceae	Sindora	*velutina*	dicot tree	1	1	2	1	1	1	2	1
Celastraceae	Kokoona	*reflexa*	dicot tree	0	1	2	2	0	1	2	2
Celastraceae	Lophopetalum	*javanicum*	dicot tree	1	0	3	6	1	0	3	6
Chrysobalanaceae	Atuna	*racemosa*	dicot tree	0	1	0	0	0	1	0	0
Chrysobalanaceae	Parinari	*canaroides*	dicot tree	1	0	1	0	1	0	1	0
Chrysobalanaceae	Parinari	*oblongifolia*	dicot tree	1	0	1	0	1	0	1	0
Crypteroniaceae	Crypteronia	*borneensis*	dicot tree	1	0	0	0	1	0	0	0
Crypteroniaceae	*Crypteronia*	griffithii	dicot tree	2	2	0	0	2	2	0	0
Dilleniaceae	*Dillenia*	excelsa	dicot tree	7	0	1	0	5	0	1	0
Dilleniaceae	*Dillenia*	reticulata	dicot tree	0	0	1	0	0	0	1	0
Dipterocarpaceae	*Anisoptera*	costata	dicot tree	0	0	1	5	0	0	1	4
Dipterocarpaceae	*Cotylelobium*	melanoxylum	dicot tree	1	0	1	4	1	0	1	4
Dipterocarpaceae	*Dipterocarpus*	acutangulus	dicot tree	2	0	3	1	2	0	3	1
Dipterocarpaceae	*Dipterocarpus*	confertus	dicot tree	3	0	1	1	3	0	1	1
Dipterocarpaceae	*Dipterocarpus*	crinitus	dicot tree	0	0	0	1	0	0	0	1
Dipterocarpaceae	*Dipterocarpus*	eurynchus	dicot tree	1	0	0	0	1	0	0	0
Dipterocarpaceae	*Dipterocarpus*	grandiflorus	dicot tree	0	0	4	4	0	0	4	4
Dipterocarpaceae	*Dipterocarpus*	lowii	dicot tree	9	0	0	0	9	0	0	0
Dipterocarpaceae	*Dipterocarpus*	palembanicus	dicot tree	0	0	0	6	0	0	0	5
Dipterocarpaceae	*Dipterocarpus*	stellatus	dicot tree	0	0	0	8	0	0	0	7
Dipterocarpaceae	*Dipterocarpus*	tempehes	dicot tree	0	1	0	0	0	1	0	0
Dipterocarpaceae	Dipterocarpus	verrucosus	dicot tree	0	0	1	1	0	0	1	1
Dipterocarpaceae	Dryobalanops	beccarii	dicot tree	0	5	0	0	0	5	0	0
Dipterocarpaceae	Dryobalanops	lanceolata	dicot tree	0	3	0	0	0	3	0	0
Dipterocarpaceae	Hopea	cernua	dicot tree	0	0	21	10	0	0	15	9
Dipterocarpaceae	Hopea	dryobalanoides	dicot tree	0	9	0	0	0	7	0	0
Dipterocarpaceae	Hopea	pachycarpa	dicot tree	2	2	3	0	2	2	3	0
Dipterocarpaceae	Hopea	semicuneata	dicot tree	76	0	0	0	54	0	0	0
Dipterocarpaceae	Parashorea	malaanonan	dicot tree	0	2	0	0	0	2	0	0
Dipterocarpaceae	Parashorea	smithisii	dicot tree	1	0	0	0	1	0	0	0
Dipterocarpaceae	Shorea	agamii	dicot tree	1	1	0	2	1	1	0	2
Dipterocarpaceae	Shorea	almon	dicot tree	0	1	1	0	0	1	1	0
Dipterocarpaceae	Shorea	atrinervosa	dicot tree	0	0	1	0	0	0	1	0
Dipterocarpaceae	Shorea	beccariana	dicot tree	0	0	4	2	0	0	4	2
Dipterocarpaceae	Shorea	collaris	dicot tree	0	0	0	1	0	0	0	1
Dipterocarpaceae	Shorea	elliptica	dicot tree	0	1	0	0	0	1	0	0
Dipterocarpaceae	Shorea	exelliptica	dicot tree	0	1	2	7	0	1	2	7

Family	Genus	Species	Plant type	N0	N1	N2	N3	S0	S1	S2	S3
Dipterocarpaceae	Shorea	hopeifolia	dicot tree	1	0	0	2	1	0	0	2
Dipterocarpaceae	Shorea	inappendiculata	dicot tree	0	0	0	10	0	0	0	8
Dipterocarpaceae	Shorea	laevis	dicot tree	0	1	1	3	0	1	1	3
Dipterocarpaceae	Shorea	leprosula	dicot tree	3	6	1	0	3	4	1	0
Dipterocarpaceae	Shorea	longisperma	dicot tree	0	0	0	1	0	0	0	1
Dipterocarpaceae	Shorea	macrophylla	dicot tree	0	0	0	4	0	0	0	3
Dipterocarpaceae	Shorea	macroptera	dicot tree	1	0	5	6	1	0	5	6
Dipterocarpaceae	Shorea	maxwelliana	dicot tree	0	0	0	6	0	0	0	6
Dipterocarpaceae	Shorea	mecistopterix	dicot tree	1	0	0	0	1	0	0	0
Dipterocarpaceae	Shorea	mujogensis	dicot tree	1	0	0	0	1	0	0	0
Dipterocarpaceae	Shorea	ovalis	dicot tree	0	0	1	1	0	0	1	1
Dipterocarpaceae	Shorea	*parvifolia*	dicot tree	1	24	6	12	1	18	6	10
Dipterocarpaceae	Shorea	*parvistipulata*	dicot tree	3	6	3	6	3	6	3	6
Dipterocarpaceae	Shorea	*patoiensis*	dicot tree	1	0	0	0	1	0	0	0
Dipterocarpaceae	Shorea	*pauciflora*	dicot tree	2	1	5	3	2	1	5	3
Dipterocarpaceae	Shorea	*pinanga*	dicot tree	3	17	6	1	3	9	5	1
Dipterocarpaceae	Shorea	*retusa*	dicot tree	0	0	1	7	0	0	1	7
Dipterocarpaceae	Shorea	*seminis*	dicot tree	0	6	0	0	0	2	0	0
Dipterocarpaceae	Shorea	*smithiana*	dicot tree	4	5	1	4	4	5	1	4
Dipterocarpaceae	Vatica	*micrantha*	dicot tree	0	3	0	0	0	2	0	0
Dipterocarpaceae	Vatica	*nitens*	dicot tree	1	0	5	13	1	0	5	13
Dipterocarpaceae	Vatica	*oblongifolia*	dicot tree	5	3	9	6	5	3	9	5
Dipterocarpaceae	Vatica	*umbonata*	dicot tree	0	0	5	0	0	0	4	0
Ebenaceae	*Diospyros*	banthamensis	dicot tree	2	0	0	0	2	0	0	0
Ebenaceae	*Diospyros*	borneensis	dicot tree	9	11	0	2	9	11	0	2
Ebenaceae	*Diospyros*	buxifolia	dicot tree	0	5	1	1	0	5	1	1
Ebenaceae	*Diospyros*	confertiflora	dicot tree	1	0	0	0	1	0	0	0
Ebenaceae	*Diospyros*	curranii	dicot tree	16	5	0	0	15	5	0	0
Ebenaceae	*Diospyros*	densa	dicot tree	0	1	1	0	0	1	1	0
Ebenaceae	*Diospyros*	pendula	dicot tree	1	0	0	0	1	0	0	0
Ebenaceae	*Diospyros*	sp.1	dicot tree	0	2	0	0	0	2	0	0
Elaeocarpaceae	*Elaeocarpus*	beccarii	dicot tree	0	1	0	0	0	1	0	0
Elaeocarpaceae	*Elaeocarpus*	macrocerus	dicot tree	0	0	0	1	0	0	0	1
Elaeocarpaceae	*Elaeocarpus*	sp.	dicot tree	0	0	0	1	0	0	0	1
Elaeocarpaceae	*Elaeocarpus*	stipularis	dicot tree	0	1	1	2	0	1	1	2
Elaeocarpaceae	*Sloanea*	javanica	dicot tree	0	1	0	0	0	1	0	0
Erythroxylaceae	*Erytroxylum*	cuneatum	dicot tree	1	1	0	0	1	1	0	0
Euphorbiaceae	Aporosa	benthamiana	dicot tree	0	1	0	0	0	1	0	0
Euphorbiaceae	Aporosa	dioica	dicot tree	3	7	2	1	3	7	2	1
Euphorbiaceae	Aporosa	nervosa	dicot tree	0	0	1	0	0	0	1	0
Euphorbiaceae	Aporosa	nitida	dicot tree	0	1	1	0	0	1	1	0
Euphorbiaceae	Baccaurea	angulata	dicot tree	0	4	0	0	0	2	0	0
Euphorbiaceae	Baccaurea	macrocarpa	dicot tree	0	7	0	0	0	6	0	0
Euphorbiaceae	Baccaurea	sumatrana	dicot tree	0	2	1	0	0	2	1	0

Family	Genus	Species	Plant type	N0	N1	N2	N3	S0	S1	S2	S3
Euphorbiaceae	Chaetocarpus	castanocarpus	dicot tree	19	4	3	12	18	4	3	12
Euphorbiaceae	Cleistanthus	erycibifolius	dicot tree	1	0	0	0	1	0	0	0
Euphorbiaceae	Cleistanthus	myrianthus	dicot tree	1	1	0	0	1	1	0	0
Euphorbiaceae	Croton	argyratus	dicot tree	6	0	0	0	5	0	0	0
Euphorbiaceae	Croton	caudatus	dicot tree	1	0	0	0	1	0	0	0
Euphorbiaceae	Drypetes	kikir	dicot tree	1	0	11	6	1	0	10	6
Euphorbiaceae	Drypetes	longifolia	dicot tree	3	4	0	0	3	4	0	0
Euphorbiaceae	Galearia	fulva	dicot tree	7	0	0	0	3	0	0	0
Euphorbiaceae	Macaranga	bancana	dicot tree	0	0	3	0	0	0	3	0
Euphorbiaceae	Macaranga	beccariana	dicot tree	0	0	4	2	0	0	3	1
Euphorbiaceae	Macaranga	gigantea	dicot tree	0	1	3	10	0	1	1	9
Euphorbiaceae	Macaranga	hypoleuca	dicot tree	0	2	5	2	0	1	5	2
Euphorbiaceae	Mallotus	muticus	dicot tree	0	5	0	0	0	5	0	0
Euphorbiaceae	Moultonianthus	leembruggianus	dicot tree	1	0	3	2	1	0	3	2
Euphorbiaceae	Neoscortechinia	kingii	dicot tree	2	2	11	10	2	2	10	9
Euphorbiaceae	Paracroton	pendulus	dicot tree	2	0	2	0	2	0	2	0
Euphorbiaceae	Pimelodendron	griffithianum	dicot tree	4	3	0	4	4	3	0	4
Euphorbiaceae	Trigonostemon	laevigatus	dicot tree	0	1	0	0	0	1	0	0
Fagaceae	Castanopsis	fulva	dicot tree	0	0	2	0	0	0	2	0
Fagaceae	Lithocarpus	coopertus	dicot tree	4	6	9	4	4	5	8	4
Fagaceae	Lithocarpus	*garciae*	dicot tree	0	5	1	0	0	4	1	0
Flacourtiaceae	Hydnocarpus	*polypetala*	dicot tree	19	0	0	0	18	0	0	0
Flacourtiaceae	Ryparosa	*kostermansii*	dicot tree	0	3	0	0	0	3	0	0
Guttiferae	Calophyllum	*gracilipes*	dicot tree	0	0	1	2	0	0	1	2
Guttiferae	Calophyllum	*soulatri*	dicot tree	0	4	0	0	0	4	0	0
Guttiferae	Calophyllum	*wallichianum*	dicot tree	4	0	3	3	4	0	3	3
Guttiferae	Garcinia	*celebica*	dicot tree	2	1	0	1	2	1	0	1
Guttiferae	Garcinia	*sp.1*	dicot tree	0	0	0	1	0	0	0	1
Guttiferae	Kayea	*borneensis*	dicot tree	13	1	0	1	13	1	0	1
Guttiferae	Mesua	*conoidea*	dicot tree	0	1	1	0	0	1	1	0
Hypericaceae	Cratoxylum	*sumatranum*	dicot tree	17	0	0	0	12	0	0	0
Icacinaceae	Stemonurus	*scorpioides*	dicot tree	4	1	1	2	4	1	1	2
Lauraceae	*Alseodaphne*	elmeri	dicot tree	1	5	14	8	1	5	14	8
Lauraceae	*Alseodaphne*	sp.	dicot tree	0	1	0	0	0	1	0	0
Lauraceae	*Beilschmiedia*	dictyoneura	dicot tree	0	2	0	0	0	2	0	0
Lauraceae	*Cinnamomum*	cuspidatum	dicot tree	0	1	0	0	0	1	0	0
Lauraceae	*Cryptocarya*	crassinervia	dicot tree	0	0	0	1	0	0	0	1
Lauraceae	*Dehaasia*	peduncularis	dicot tree	1	2	0	0	1	2	0	0
Lauraceae	*Endiandra*	kingiana	dicot tree	4	5	6	6	4	5	6	6
Lauraceae	*Eusideroxylon*	zwageri	dicot tree	0	25	0	0	0	23	0	0
Lauraceae	*Litsea*	firma	dicot tree	3	0	0	0	3	0	0	0
Lauraceae	*Litsea*	oppositifolia	dicot tree	1	0	1	0	1	0	1	0

Family	Genus	Species	Plant type	N0	N1	N2	N3	S0	S1	S2	S3
Lecythidaceae	*Barringtonia*	macrostachya	dicot tree	6	4	12	9	6	4	9	9
Lecythidaceae	*Barringtonia*	pendula	dicot tree	1	1	3	6	1	1	3	6
Lecythidaceae	*Planchonia*	vallida	dicot tree	1	0	0	0	1	0	0	0
Loganiaceae	*Fagraea*	racemosa	dicot tree	0	1	0	0	0	1	0	0
Magnoliaceae	Magnolia	candollii	dicot tree	4	1	1	0	4	1	1	0
Magnoliaceae	Magnolia	pendula	dicot tree	0	0	0	1	0	0	0	1
Malvaceae	Durio	dulcis	dicot tree	1	2	0	0	1	2	0	0
Malvaceae	Durio	graveolens	dicot tree	3	2	0	2	3	2	0	2
Malvaceae	Durio	griffithii	dicot tree	0	0	1	0	0	0	1	0
Malvaceae	Durio	oxleyanus	dicot tree	1	1	0	1	1	1	0	1
Malvaceae	Durio	testudinarius	dicot tree	0	1	0	0	0	1	0	0
Melastomataceae	Memecylon	borneensis	dicot tree	1	2	5	0	1	2	5	0
Melastomataceae	Memecylon	edule	dicot tree	4	0	0	0	4	0	0	0
Melastomataceae	Memecylon	oleaefolium	dicot tree	0	0	2	1	0	0	2	1
Melastomataceae	Pternandra	azurea	dicot tree	1	0	1	0	1	0	1	0
Melastomataceae	Pternandra	galeata	dicot tree	0	0	0	1	0	0	0	1
Melastomataceae	Pternandra	rostrata	dicot tree	0	2	1	2	0	2	1	2
Meliaceae	Aglaia	pachyphylla	dicot tree	2	4	0	0	2	4	0	0
Meliaceae	Aglaia	shawiana	dicot tree	1	1	0	0	1	1	0	0
Meliaceae	Aglaia	simplicifolia	dicot tree	0	1	0	0	0	1	0	0
Meliaceae	Aglaia	sp.1	dicot tree	0	0	1	0	0	0	1	0
Meliaceae	Aglaia	tomentosa	dicot tree	0	1	1	0	0	1	1	0
Meliaceae	Chisocheton	sp.	dicot tree	0	1	0	0	0	1	0	0
Mimosaceae	Archidendron	cockburnii	dicot tree	3	4	0	0	3	4	0	0
Mimosaceae	Parkia	speciosa	dicot tree	1	0	2	0	1	0	2	0
Moraceae	Artocarpus	anisophyllus	dicot tree	4	0	1	5	4	0	1	5
Moraceae	Artocarpus	elasticus	dicot tree	5	6	7	2	5	6	7	2
Moraceae	Artocarpus	lanceifolius	dicot tree	1	5	0	0	1	5	0	0
Moraceae	Ficus	variegata	dicot tree	0	0	0	1	0	0	0	1
Moraceae	Parartocarpus	bracteatus	dicot tree	2	2	1	0	2	2	1	0
Myristicaceae	Gymnacranthera	farquhariana	dicot tree	5	12	2	3	5	11	2	3
Myristicaceae	Horsfieldia	*borneensis*	dicot tree	0	0	1	0	0	0	1	0
Myristicaceae	Horsfieldia	*polyspherula*	dicot tree	0	1	14	4	0	1	13	4
Myristicaceae	Knema	*elmeri*	dicot tree	1	0	2	1	1	0	2	1
Myristicaceae	Knema	*furfuracea*	dicot tree	3	0	0	1	3	0	0	1
Myristicaceae	Knema	*laurina*	dicot tree	8	16	1	2	7	15	1	2
Myristicaceae	Knema	*subhirtella*	dicot tree	0	0	1	0	0	0	1	0
Myristicaceae	Myristica	*iners*	dicot tree	2	9	1	0	2	9	1	0
Myristicaceae	Myristica	*villosa*	dicot tree	1	5	3	12	1	5	3	12
Myrsinaceae	Ardisia	*korthalsiana*	dicot tree	0	0	1	1	0	0	1	1
Myrsinaceae	Ardisia	*sp.*	dicot tree	0	1	0	0	0	1	0	0
Myrtaceae	Syzygium	*caudatilimba*	dicot tree	5	8	1	0	5	8	1	0
Myrtaceae	Syzygium	*leptostemon*	dicot tree	0	0	0	1	0	0	0	1

Family	Genus	Species	Plant type	N0	N1	N2	N3	S0	S1	S2	S3
Myrtaceae	*Syzygium*	sp.	dicot tree	1	0	0	0	1	0	0	0
Myrtaceae	*Syzygium*	sp.1	dicot tree	0	1	0	0	0	1	0	0
Myrtaceae	*Syzygium*	sp.2	dicot tree	0	1	1	1	0	1	1	1
Myrtaceae	*Syzygium*	sp.3	dicot tree	0	1	0	0	0	1	0	0
Myrtaceae	*Syzygium*	sp.4	dicot tree	0	3	1	5	0	3	1	5
Myrtaceae	*Syzygium*	tawahense	dicot tree	16	15	42	21	13	14	32	20
Myrtaceae	*Tristaniopsis*	whitiana	dicot tree	1	0	0	0	1	0	0	0
Olacaceae	*Ochanostachys*	amentacea	dicot tree	0	1	1	1	0	1	1	1
Olacaceae	*Strombosia*	ceylanica	dicot tree	3	1	2	7	3	1	2	7
Oleaceae	*Chionanthus*	sp.1	dicot tree	15	2	9	0	14	2	9	0
Oleaceae	*Chionanthus*	sp.2	dicot tree	1	0	0	0	1	0	0	0
Oxalidaceae	*Sarcotheca*	diversifolia	dicot tree	1	0	1	3	1	0	1	3
Oxalidaceae	*Sarcotheca*	rubrinervis	dicot tree	4	4	2	0	4	4	2	0
Palmae	*Oncosperma*	horidum	palm tree	0	7	0	3	0	5	0	1
Papilionaceae	Fordia	splendidissima	dicot tree	1	0	0	0	1	0	0	0
Polygalaceae	Xanthophyllum	affine	dicot tree	2	0	7	2	2	0	7	2
Polygalaceae	Xanthophyllum	clovis	dicot tree	1	0	0	0	1	0	0	0
Polygalaceae	Xanthophyllum	obscurum	dicot tree	4	1	3	4	3	1	2	4
Polygalaceae	Xanthophyllum	rufum	dicot tree	0	0	1	0	0	0	1	0
Polygalaceae	Xanthophyllum	stipitatum	dicot tree	1	0	0	1	1	0	0	1
Rhizophoraceae	Anisophyllea	corneri	dicot tree	1	0	3	1	1	0	2	1
Rhizophoraceae	Carallia	brachiata	dicot tree	0	1	0	0	0	1	0	0
Rosaceae	Prunus	beccarii	dicot tree	1	2	2	0	1	2	2	0
Rubiaceae	Anthocephalus	chinensis	dicot tree	0	1	1	0	0	1	1	0
Rubiaceae	Gardenia	tubifera	dicot tree	3	1	0	0	3	1	0	0
Rubiaceae	Hypobathrum	sp.	dicot tree	0	0	1	0	0	0	1	0
Rubiaceae	Musaendopsis	sp.	dicot tree	2	0	0	0	2	0	0	0
Rubiaceae	Nauclea	subdita	dicot tree	1	3	2	0	1	3	2	0
Rubiaceae	Neonauclea	gigantea	dicot tree	0	1	0	0	0	1	0	0
Rubiaceae	Pertusadina	eurycha	dicot tree	0	0	0	1	0	0	0	1
Rubiaceae	Porterandia	anisophylla	dicot tree	0	1	0	1	0	1	0	1
Rubiaceae	Rothmannia	schoemanii	dicot tree	0	1	0	0	0	1	0	0
Rubiaceae	Tarenna	rostrata	dicot tree	0	1	0	0	0	1	0	0
Rubiaceae	Timonius	flavescens	dicot tree	2	0	1	0	2	0	1	0
Rubiaceae	Urophyllum	arborescens	dicot tree	0	1	0	0	0	1	0	0
Sapindaceae	Dimocarpus	longan	dicot tree	1	3	0	0	1	3	0	0
Sapindaceae	Nephelium	laurinum	dicot tree	2	0	0	2	2	0	0	2
Sapindaceae	Nephelium	rambutan-ake	dicot tree	0	2	0	0	0	2	0	0
Sapindaceae	Paranephelium	xestophyllum	dicot tree	0	1	0	0	0	1	0	0
Sapindaceae	Pometia	pinnata	dicot tree	5	0	1	0	5	0	1	0
Sapindaceae	Xerospermum	noronhianum	dicot tree	0	0	0	3	0	0	0	3

Family	Genus	Species	Plant type	N0	N1	N2	N3	S0	S1	S2	S3
Sapotaceae	Madhuca	*kingiana*	dicot tree	5	1	5	0	5	1	5	0
Sapotaceae	Madhuca	*malaccensis*	dicot tree	8	1	46	58	7	1	37	42
Sapotaceae	Madhuca	*sericea*	dicot tree	1	0	5	2	1	0	5	2
Sapotaceae	Madhuca	*sessilis*	dicot tree	5	1	0	0	5	1	0	0
Sapotaceae	Palaquium	*beccarianum*	dicot tree	1	0	0	0	1	0	0	0
Sapotaceae	Palaquium	*borneensis*	dicot tree	0	1	0	0	0	1	0	0
Sapotaceae	Palaquium	*calophyllum*	dicot tree	0	16	5	5	0	14	5	4
Sapotaceae	Palaquium	*quercifolium*	dicot tree	0	1	0	0	0	1	0	0
Sapotaceae	Palaquium	*sp.1*	dicot tree	0	0	1	0	0	0	1	0
Sapotaceae	Palaquium	*stenophyllum*	dicot tree	12	1	7	6	12	1	6	6
Sapotaceae	Payena	*acuminata*	dicot tree	0	0	0	1	0	0	0	1
Simaroubaceae	Allanthospermum	*borneensis*	dicot tree	0	0	0	47	0	0	0	42
Simaroubaceae	*Irvingia*	malayana	dicot tree	0	0	0	1	0	0	0	1
Sterculiaceae	Heritiera	elata	dicot tree	6	0	2	1	6	0	2	1
Sterculiaceae	Heritiera	symplicifolia	dicot tree	1	0	4	2	1	0	4	2
Sterculiaceae	Scaphium	*macropodum*	dicot tree	3	3	3	10	3	3	3	10
Sterculiaceae	Sterculia	*macrophylla*	dicot tree	1	0	1	0	1	0	1	0
Sterculiaceae	Sterculia	*rubiginosa*	dicot tree	3	2	1	1	3	2	1	1
Symplocaceae	Symplocos	*crassipes*	dicot tree	2	1	0	0	2	1	0	0
Theaceae	Tetramerista	*glabra*	dicot tree	0	0	3	0	0	0	3	0
Thymelaeaceae	Gonystylus	*bancanus*	dicot tree	2	0	1	0	2	0	1	0
Thymelaeaceae	Gonystylus	*macrophyllus*	dicot tree	5	2	0	4	5	2	0	4
Tiliaceae	Grewia	*fibrocarpa*	dicot tree	0	2	0	0	0	2	0	0
Tiliaceae	Microcos	*crassifolia*	dicot tree	0	3	1	0	0	3	1	0
Tiliaceae	Pentace	*adenophora*	dicot tree	3	1	1	0	3	1	1	0
Tiliaceae	Pentace	*laxiflora*	dicot tree	0	1	2	1	0	1	2	1
Tiliaceae	Pentace	*polyantha*	dicot tree	2	0	0	2	1	0	0	2
Ulmaceae	Gironniera	*nervosa*	dicot tree	3	3	10	9	3	3	10	9
Verbenaceae	Teijsmanniodendron	*coriaceum*	dicot tree	32	0	0	0	23	0	0	0
Verbenaceae	Teijsmanniodendron	*pteropodium*	dicot tree	7	0	1	0	7	0	1	0

Appendix 2

List of all saplings species recorded in the 5 x 5 m subplot. After each family, genus and species name respectively plant type, observed number of stems (N) and number of subplots having at least on stem exceeding dbh < 10 cm in height ≥ 1.5 m of this species (S) per forest disturbance type (0 = primary forest, 1 = secondary forest, 1 year after logged, 2 = 5 years after logged, 3 = 10 years after logged.

Family	Genus	Species	Plant type	N0	N1	N2	N3	S0	S1	S2	S3
Anacardiaceae	*Buchanania*	sessifolia	dicot tree	0	1	0	2	0	1	0	2
Anacardiaceae	*Drimycarpus*	luridus	dicot tree	1	1	0	1	1	1	0	1
Anacardiaceae	*Gluta*	renghas	dicot tree	1	0	0	7	1	0	0	3
Anacardiaceae	*Koordersiodendron*	pinnatum	dicot tree	0	1	1	0	0	1	1	0
Anacardiaceae	*Mangifera*	pajang	dicot tree	3	0	0	0	3	0	0	0
Annonaceae	*Anaxagorea*	javanica	dicot tree	4	0	0	0	3	0	0	0
Annonaceae	*Goniothalamus*	macrophyllus	dicot tree	1	0	0	0	1	0	0	0
Annonaceae	*Mezzettia*	parviflora	dicot tree	1	0	2	2	1	0	2	2
Annonaceae	*Polyalthia*	cauliflora	dicot tree	0	3	0	0	0	3	0	0
Annonaceae	*Polyalthia*	lateriflora	dicot tree	0	1	0	0	0	1	0	0
Annonaceae	*Polyalthia*	microtus	dicot tree	0	1	0	0	0	1	0	0
Annonaceae	*Polyalthia*	rumphii	dicot tree	2	0	2	1	2	0	2	1
Annonaceae	*Popowia*	hirta	dicot tree	3	0	0	0	2	0	0	0
Annonaceae	*Popowia*	pisocarpa	dicot tree	0	0	0	1	0	0	0	1
Annonaceae	*Sageraea*	lanceolata	dicot tree	0	0	1	1	0	0	1	1
Annonaceae	*Xylopia*	ferruginea	dicot tree	5	2	4	0	5	2	4	0
Apocynaceae	*Alstonia*	iwahigensis	dicot tree	0	0	0	1	0	0	0	1
Bignoniaceae	*Radermachera*	pinnata	dicot tree	1	0	0	0	1	0	0	0
Burseraceae	*Canarium*	denticulatum	dicot tree	0	0	6	4	0	0	5	2
Burseraceae	Canarium	littorale	dicot tree	2	0	2	1	2	0	2	1
Burseraceae	Canarium	megalanthum	dicot tree	0	0	0	1	0	0	0	1
Burseraceae	Dacryodes	rostrata	dicot tree	4	3	4	2	3	3	3	2
Burseraceae	Dacryodes	rugosa	dicot tree	1	0	1	0	1	0	1	0
Burseraceae	Santiria	griffithii	dicot tree	0	0	0	1	0	0	0	1
Caesalpiniaceae	Cynometra	elmeri	dicot tree	0	2	0	0	0	2	0	0
Caesalpiniaceae	Koompassia	malaccensis	dicot tree	0	0	1	0	0	0	1	0
Caesalpiniaceae	Saraca	declinata	dicot tree	2	0	0	0	1	0	0	0
Caesalpiniaceae	Sindora	velutina	dicot tree	0	1	0	0	0	1	0	0
Celastraceae	Lophopetalum	javanicum	dicot tree	0	1	0	3	0	1	0	2
Chrysobalanaceae	Parinari	canaroides	dicot tree	4	0	1	0	3	0	1	0
Chrysobalanaceae	Parinari	oblongifolia	dicot tree	0	1	0	0	0	1	0	0
Compositae	Vernonia	*arborea*	dicot tree	0	0	0	1	0	0	0	1
Crypteroniaceae	Crypteronia	*griffithii*	dicot tree	1	1	3	0	1	1	3	0

Family	Genus	Species	Plant type	N0	N1	N2	N3	S0	S1	S2	S3
Dilleniaceae	Dillenia	*excelsa*	dicot tree	3	0	0	0	2	0	0	0
Dilleniaceae	Dillenia	*reticulata*	dicot tree	1	0	1	1	1	0	1	1
Dilleniaceae	Dillenia	*suffruticosa*	dicot tree	0	1	0	0	0	1	0	0
Dipterocarpaceae	Cotylelobium	*melanoxylum*	dicot tree	0	0	2	1	0	0	2	1
Dipterocarpaceae	Dipterocarpus	*acutangulus*	dicot tree	4	0	2	0	3	0	1	0
Dipterocarpaceae	Dipterocarpus	*grandiflorus*	dicot tree	0	0	0	1	0	0	0	1
Dipterocarpaceae	Dipterocarpus	*palembanicus*	dicot tree	0	0	0	2	0	0	0	2
Dipterocarpaceae	Dipterocarpus	*tempehes*	dicot tree	1	0	0	0	1	0	0	0
Dipterocarpaceae	Dryobalanops	*beccarii*	dicot tree	0	1	0	0	0	1	0	0
Dipterocarpaceae	Hopea	*cernua*	dicot tree	0	0	0	2	0	0	0	1
Dipterocarpaceae	Hopea	*pachycarpa*	dicot tree	0	0	1	0	0	0	1	0
Dipterocarpaceae	Hopea	*semicuneata*	dicot tree	10	0	0	0	3	0	0	0
Dipterocarpaceae	Shorea	*agamii*	dicot tree	0	0	1	0	0	0	1	0
Dipterocarpaceae	Shorea	*angustifolia*	dicot tree	1	5	0	0	1	1	0	0
Dipterocarpaceae	Shorea	*atrinervosa*	dicot tree	0	0	0	5	0	0	0	3
Dipterocarpaceae	*Shorea*	beccariana	dicot tree	0	0	0	1	0	0	0	1
Dipterocarpaceae	*Shorea*	collaris	dicot tree	0	0	4	0	0	0	2	0
Dipterocarpaceae	*Shorea*	guiso	dicot tree	1	0	0	0	1	0	0	0
Dipterocarpaceae	*Shorea*	macroptera	dicot tree	1	0	0	10	1	0	0	3
Dipterocarpaceae	*Shorea*	maxwelliana	dicot tree	0	0	0	1	0	0	0	1
Dipterocarpaceae	*Shorea*	mujogensis	dicot tree	0	5	0	0	0	1	0	0
Dipterocarpaceae	*Shorea*	ovalis	dicot tree	1	0	0	0	1	0	0	0
Dipterocarpaceae	*Shorea*	parvifolia	dicot tree	0	5	6	4	0	3	4	4
Dipterocarpaceae	*Shorea*	parvistipulata	dicot tree	0	1	0	2	0	1	0	1
Dipterocarpaceae	*Shorea*	patoiensis	dicot tree	1	0	0	2	1	0	0	1
Dipterocarpaceae	*Shorea*	pauciflora	dicot tree	0	0	1	0	0	0	1	0
Dipterocarpaceae	*Shorea*	pinanga	dicot tree	0	6	3	0	0	3	3	0
Dipterocarpaceae	*Shorea*	smithiana	dicot tree	0	1	6	0	0	1	3	0
Dipterocarpaceae	*Vatica*	nitens	dicot tree	0	0	4	0	0	0	2	0
Dipterocarpaceae	Vatica	oblongifolia	dicot tree	4	0	7	3	4	0	5	3
Dipterocarpaceae	Vatica	umbonata	dicot tree	0	0	1	1	0	0	1	1
Ebenaceae	Diospyros	borneensis	dicot tree	2	6	1	0	2	4	1	0
Ebenaceae	Diospyros	buxifolia	dicot tree	1	1	2	1	1	1	2	1
Ebenaceae	Diospyros	curranii	dicot tree	3	0	2	0	3	0	2	0
Ebenaceae	Diospyros	macrophylla	dicot tree	6	0	0	0	3	0	0	0
Ebenaceae	Diospyros	sp.1	dicot tree	0	2	0	0	0	1	0	0
Elaeocarpaceae	Elaeocarpus	roslii	dicot tree	0	0	0	1	0	0	0	1
Elaeocarpaceae	Elaeocarpus	stipularis	dicot tree	1	0	0	0	1	0	0	0
Erythroxylaceae	Erytroxylum	cuneatum	dicot tree	1	0	0	0	1	0	0	0
Euphorbiaceae	Antidesma	montanum	dicot tree	3	4	0	0	2	4	0	0
Euphorbiaceae	Antidesma	neurocarpum	dicot tree	0	3	0	0	0	1	0	0
Euphorbiaceae	Aporosa	dioica	dicot tree	0	0	2	4	0	0	2	3
Euphorbiaceae	Aporosa	nitida	dicot tree	1	1	2	0	1	1	2	0
Euphorbiaceae	Baccaurea	macrocarpa	dicot tree	0	2	0	0	0	1	0	0

Family	Genus	Species	Plant type	N0	N1	N2	N3	S0	S1	S2	S3
Euphorbiaceae	Baccaurea	sumatrana	dicot tree	2	2	0	1	2	2	0	1
Euphorbiaceae	Baccaurea	tetrandra	dicot tree	0	0	0	2	0	0	0	1
Euphorbiaceae	Chaetocarpus	castanocarpus	dicot tree	3	0	3	0	3	0	3	0
Euphorbiaceae	Cleistanthus	erycibifolius	dicot tree	4	0	10	2	4	0	8	2
Euphorbiaceae	Cleistanthus	myrianthus	dicot tree	3	0	0	0	3	0	0	0
Euphorbiaceae	Croton	argyratus	dicot tree	5	0	0	0	3	0	0	0
Euphorbiaceae	Croton	caudatus	dicot tree	1	0	0	2	1	0	0	2
Euphorbiaceae	Drypetes	kikir	dicot tree	0	0	1	0	0	0	1	0
Euphorbiaceae	Drypetes	longifolia	dicot tree	1	1	0	0	1	1	0	0
Euphorbiaceae	Galearia	fulva	dicot tree	3	0	0	0	2	0	0	0
Euphorbiaceae	Glochidion	arborescens	dicot tree	2	25	2	0	2	4	2	0
Euphorbiaceae	Glochidion	calospermum	dicot tree	0	7	0	0	0	3	0	0
Euphorbiaceae	Koilodepas	*brevipes*	dicot tree	7	10	15	6	6	3	6	4
Euphorbiaceae	Macaranga	*bancana*	dicot tree	0	0	0	1	0	0	0	1
Euphorbiaceae	Macaranga	*beccariana*	dicot tree	1	0	0	0	1	0	0	0
Euphorbiaceae	Macaranga	*cf. repando-dentata*	dicot tree	0	1	0	0	0	1	0	0
Euphorbiaceae	Macaranga	*conifera*	dicot tree	0	0	0	1	0	0	0	1
Euphorbiaceae	Macaranga	*gigantea*	dicot tree	0	12	0	3	0	4	0	2
Euphorbiaceae	Macaranga	*hypoleuca*	dicot tree	0	24	3	5	0	4	3	1
Euphorbiaceae	Macaranga	*lowii*	dicot tree	0	0	1	2	0	0	1	1
Euphorbiaceae	Mallotus	*muticus*	dicot tree	4	1	0	4	2	1	0	3
Euphorbiaceae	Mallotus	*penangensis*	dicot tree	0	0	0	2	0	0	0	2
Euphorbiaceae	Moultonianthus	*leembruggianus*	dicot tree	0	0	1	0	0	0	1	0
Euphorbiaceae	Neoscortechinia	*kingii*	dicot tree	1	0	3	0	1	0	2	0
Euphorbiaceae	*Pimelodendron*	griffithianum	dicot tree	2	0	0	0	2	0	0	0
Fagaceae	*Castanopsis*	fulva	dicot tree	0	0	1	0	0	0	1	0
Fagaceae	*Lithocarpus*	coopertus	dicot tree	0	0	3	3	0	0	3	2
Flacourtiaceae	*Hydnocarpus*	polypetala	dicot tree	1	0	0	1	1	0	0	1
Guttiferae	*Calophyllum*	gracilipes	dicot tree	0	0	4	2	0	0	3	2
Guttiferae	*Calophyllum*	sp.	dicot tree	0	1	0	0	0	1	0	0
Guttiferae	*Calophyllum*	wallichianum	dicot tree	1	0	4	1	1	0	3	1
Guttiferae	*Garcinia*	celebica	dicot tree	0	0	0	3	0	0	0	3
Guttiferae	*Kayea*	borneensis	dicot tree	3	1	0	1	3	1	0	1
Guttiferae	*Mesua*	conoidea	dicot tree	1	1	0	0	1	1	0	0
Hypericaceae	*Cratoxylum*	sumatranum	dicot tree	3	0	2	0	2	0	2	0
Icacinaceae	*Stemonurus*	scorpioides	dicot tree	5	0	0	0	4	0	0	0
Lauraceae	*Actinodaphne*	diadenum	dicot tree	0	2	0	0	0	1	0	0
Lauraceae	*Alseodaphne*	elmeri	dicot tree	2	0	6	3	1	0	5	2
Lauraceae	Cinnamomum	cuspidatum	dicot tree	0	0	1	0	0	0	1	0
Lauraceae	Cryptocarya	crassinervia	dicot tree	0	1	0	0	0	1	0	0
Lauraceae	Endiandra	kingiana	dicot tree	0	1	0	1	0	1	0	1

Family	Genus	Species	Plant type	N0	N1	N2	N3	S0	S1	S2	S3
Lauraceae	Eusideroxylon	zwageri	dicot tree	0	1	0	0	0	1	0	0
Lauraceae	Litsea	angulata	dicot tree	0	0	0	1	0	0	0	1
Lauraceae	Litsea	firma	dicot tree	0	0	4	0	0	0	3	0
Lauraceae	Litsea	oppositifolia	dicot tree	0	0	0	1	0	0	0	1
Lauraceae	Phoebe	grandis	dicot tree	0	1	1	0	0	1	1	0
Lecythidaceae	Barringtonia	macrostachya	dicot tree	0	0	2	3	0	0	2	3
Loganiaceae	Fagraea	racemosa	dicot tree	2	2	0	0	1	1	0	0
Magnoliaceae	Magnolia	candollii	dicot tree	3	0	0	0	2	0	0	0
Malvaceae	Durio	dulcis	dicot tree	0	0	0	1	0	0	0	1
Malvaceae	Durio	graveolens	dicot tree	1	0	0	0	1	0	0	0
Malvaceae	Durio	griffithii	dicot tree	0	0	1	0	0	0	1	0
Malvaceae	Durio	oxleyanus	dicot tree	1	0	0	0	1	0	0	0
Malvaceae	Nessia	cynandra	dicot tree	1	0	0	0	1	0	0	0
Melastomataceae	Melastoma	malabathricum	dicot tree	0	1	3	27	0	1	1	3
Melastomataceae	Memecylon	borneensis	dicot tree	6	0	3	1	4	0	2	1
Melastomataceae	Memecylon	oleaefolium	dicot tree	0	0	0	1	0	0	0	1
Melastomataceae	Pternandra	azurea	dicot tree	1	0	2	1	1	0	2	1
Melastomataceae	Pternandra	rostrata	dicot tree	0	1	2	1	0	1	2	1
Meliaceae	Aglaia	pachyphylla	dicot tree	1	0	0	0	1	0	0	0
Meliaceae	Aglaia	sp.1	dicot tree	3	0	1	0	3	0	1	0
Meliaceae	Aglaia	tomentosa	dicot tree	3	0	1	0	3	0	1	0
Meliaceae	Chisocheton	sp.	dicot tree	0	1	1	0	0	1	1	0
Meliaceae	Dysoxylum	alliaceum	dicot tree	0	2	0	0	0	1	0	0
Meliaceae	Dysoxylum	cauliflorum	dicot tree	0	1	0	0	0	1	0	0
Moraceae	Artocarpus	*elasticus*	dicot tree	0	1	0	0	0	1	0	0
Moraceae	Artocarpus	*integer*	dicot tree	0	1	0	0	0	1	0	0
Moraceae	Artocarpus	*lanceifolius*	dicot tree	0	0	1	0	0	0	1	0
Moraceae	Ficus	*obscura*	dicot tree	0	2	0	0	0	2	0	0
Myristicaceae	Horsfieldia	*cornosa*	dicot tree	0	0	0	1	0	0	0	1
Myristicaceae	Horsfieldia	*polyspherula*	dicot tree	0	3	2	1	0	3	2	1
Myristicaceae	Knema	*elmeri*	dicot tree	1	0	0	2	1	0	0	2
Myristicaceae	Knema	*furfuracea*	dicot tree	0	1	1	0	0	1	1	0
Myristicaceae	Knema	*laurina*	dicot tree	7	3	1	2	6	3	1	2
Myristicaceae	Myristica	*iners*	dicot tree	0	3	0	0	0	1	0	0
Myristicaceae	Myristica	*villosa*	dicot tree	2	0	0	0	2	0	0	0
Myrsinaceae	Ardisia	*korthalsiana*	dicot tree	0	1	1	1	0	1	1	1
Myrsinaceae	*Ardisia*	sp.1	dicot tree	0	2	0	0	0	1	0	0
Myrtaceae	*Syzygium*	caudatilimba	dicot tree	1	2	0	0	1	1	0	0
Myrtaceae	*Syzygium*	sp.2	dicot tree	0	1	0	0	0	1	0	0
Myrtaceae	*Syzygium*	sp.3	dicot tree	3	0	0	0	1	0	0	0
Myrtaceae	*Syzygium*	sp.4	dicot tree	2	1	1	0	1	1	1	0
Myrtaceae	*Syzygium*	tawahense	dicot tree	5	7	9	11	3	4	6	7

Family	Genus	Species	Plant type	N0	N1	N2	N3	S0	S1	S2	S3
Ochnaceae	*Gomphia*	serrata	dicot tree	2	0	1	0	2	0	1	0
Olacaceae	*Ochanostachys*	amentacea	dicot tree	0	2	0	0	0	2	0	0
Oleaceae	*Chionanthus*	sp.1	dicot tree	8	6	3	1	5	3	2	1
Oleaceae	*Chionanthus*	sp.2	dicot tree	2	0	0	0	1	0	0	0
Oxalidaceae	*Sarcotheca*	diversifolia	dicot tree	0	1	3	0	0	1	3	0
Oxalidaceae	*Sarcotheca*	rubrinervis	dicot tree	0	1	1	0	0	1	1	0
Papilionaceae	*Fordia*	splendidissima	dicot tree	11	5	6	7	5	4	5	5
Polygalaceae	*Xanthophyllum*	affine	dicot tree	6	0	1	3	5	0	1	2
Polygalaceae	Xanthophyllum	griffithii	dicot tree	0	0	2	0	0	0	2	0
Polygalaceae	Xanthophyllum	obscurum	dicot tree	3	0	2	5	2	0	2	4
Rhizophoraceae	Anisophyllea	corneri	dicot tree	0	2	0	1	0	2	0	1
Rubiaceae	Anthocephalus	chinensis	dicot tree	0	3	0	0	0	2	0	0
Rubiaceae	Hypobathrum	sp.	dicot tree	4	4	1	2	4	4	1	1
Rubiaceae	Ixora	fucosa	dicot shrub	1	2	11	5	1	2	6	3
Rubiaceae	Nauclea	subdita	dicot tree	0	0	1	0	0	0	1	0
Rubiaceae	Neonauclea	gigantea	dicot tree	0	0	0	1	0	0	0	1
Rubiaceae	Tarenna	rostrata	dicot tree	0	0	0	2	0	0	0	1
Rubiaceae	Timonius	flavescens	dicot tree	0	0	2	2	0	0	2	2
Rubiaceae	Uncaria	borneensis	dicot liana	0	0	0	2	0	0	0	1
Rubiaceae	Uncaria	calophylla	dicot liana	0	0	0	3	0	0	0	1
Rubiaceae	Uncaria	cordata	dicot liana	0	6	0	0	0	1	0	0
Rubiaceae	Urophyllum	arborescens	dicot tree	2	2	0	1	2	2	0	1
Sapindaceae	Dimocarpus	longan	dicot tree	1	1	0	0	1	1	0	0
Sapindaceae	Guioa	sp.	dicot tree	1	0	0	0	1	0	0	0
Sapindaceae	Lepisanthes	amoena	dicot tree	0	1	0	1	0	1	0	1
Sapindaceae	Mischocarpus	pentapetalus	dicot tree	1	0	0	0	1	0	0	0
Sapindaceae	Nephelium	laurinum	dicot tree	0	0	0	1	0	0	0	1
Sapindaceae	Xerospermum	noronhianum	dicot tree	1	0	0	0	1	0	0	0
Sapotaceae	Madhuca	kingiana	dicot tree	1	0	2	0	1	0	2	0
Sapotaceae	Madhuca	malaccensis	dicot tree	5	0	22	11	4	0	7	5
Sapotaceae	Madhuca	sericea	dicot tree	0	0	2	1	0	0	2	1
Sapotaceae	Palaquium	calophyllum	dicot tree	1	3	0	0	1	3	0	0
Sapotaceae	Palaquium	stenophyllum	dicot tree	4	3	0	3	4	2	0	2
Scrophulariaceae	Brookea	sp.	dicot tree	0	1	0	1	0	1	0	1
Simaroubaceae	Allanthospermum	*borneensis*	dicot tree	0	0	0	1	0	0	0	1
Simaroubaceae	Eurycoma	*longifolia*	dicot tree	0	0	1	0	0	0	1	0
Sterculiaceae	Heritiera	*symplicifolia*	dicot tree	1	0	0	0	1	0	0	0
Sterculiaceae	Scaphium	*macropodum*	dicot tree	1	0	1	4	1	0	1	3
Symplocaceae	Symplocos	*crassipes*	dicot tree	0	0	0	1	0	0	0	1

Family	Genus	Species	Plant type	N0	N1	N2	N3	S0	S1	S2	S3
Theaceae	Tetramerista	*glabra*	dicot tree	1	0	0	0	1	0	0	0
Thymelaeaceae	Aquilaria	*malaccensis*	dicot tree	0	1	0	0	0	1	0	0
Thymelaeaceae	Gonystylus	*macrophyllus*	dicot tree	1	0	2	1	1	0	2	1
Tiliaceae	Microcos	*crassifolia*	dicot tree	0	3	1	0	0	2	1	0
Tiliaceae	Pentace	*adenophora*	dicot tree	0	3	0	0	0	3	0	0
Ulmaceae	Gironniera	*nervosa*	dicot tree	1	3	3	7	1	3	3	5
Verbenaceae	Teijsmanniodendron	*pteropodium*	dicot tree	5	0	1	5	5	0	1	3
Vitaceae	*Leea*	*aculeata*	dicot shrub	1	1	0	0	1	1	0	0
Zingiberaceae	*Costus*	*speciosus*	Monocot herb	0	2	0	0	0	1	0	0

Appendix 3

List of all seedlings species recorded in the 2 × 2 m subplot. After each family, genus and species name respectively plant type, observed number of stems (N) and number of subplots having at least on stem exceeding young trees of up to 1.5 m in height of this species (S) per forest disturbance type (0 = primary forest, 1 = secondary forest, 1 year after logged, 2 = 5 years after logged, 3 = 10 years after logged.

Family	Genus	Species	Plant type	N0	N1	N2	N3	S0	S1	S2	S3
Actinidiaceae	Saurauia	sp.1	dicot tree	0	1	0	0	0	1	0	0
Anacardiaceae	Bouea	oppositifolia	dicot tree	3	1	0	0	1	1	0	0
Anacardiaceae	Buchanania	sessifolia	dicot tree	0	1	0	0	0	1	0	0
Anacardiaceae	Drimycarpus	luridus	dicot tree	0	1	0	1	0	1	0	1
Anacardiaceae	Gluta	renghas	dicot tree	0	0	7	9	0	0	4	2
Anacardiaceae	Koordersiodendron	pinnatum	dicot tree	0	3	0	2	0	3	0	1
Anacardiaceae	Mangifera	torquendra	dicot tree	3	0	0	0	2	0	0	0
Anacardiaceae	Semecarpus	glaucous	dicot tree	0	1	0	0	0	1	0	0
Annonaceae	Anaxagorea	javanica	dicot tree	4	0	1	0	4	0	1	0
Annonaceae	Desmos	cochinchinensis	dicot liana	0	2	1	0	0	1	1	0
Annonaceae	Mezzettia	parviflora	dicot tree	0	0	1	2	0	0	1	1
Annonaceae	Mitrephora	korthalsiana	dicot tree	0	0	0	1	0	0	0	1
Annonaceae	Polyalthia	cauliflora	dicot tree	0	0	1	0	0	0	1	0
Annonaceae	Popowia	hirta	dicot tree	1	0	0	0	1	0	0	0
Annonaceae	Uvaria	elmeri	dicot liana	7	0	0	0	3	0	0	0
Annonaceae	Xylopia	ferruginea	dicot tree	8	0	0	0	2	0	0	0
Apocynaceae	Alstonia	iwahigensis	dicot tree	0	1	1	3	0	1	1	1
Apocynaceae	Willughbeia	angustifolia	dicot liana	0	0	2	0	0	0	1	0
Araceae	Photos	sp.	monocot liana	1	0	0	0	1	0	0	0
Araceae	Syngonium	macrophyllum	monocot herb	1	0	0	0	1	0	0	0
Bignoniaceae	Radermachera	pinnata	dicot tree	2	0	0	0	1	0	0	0
Blechnaceae	Stenochlaena	palustris	fern liana	0	0	9	2	0	0	1	2
Burseraceae	Canarium	denticulatum	dicot tree	2	0	1	2	1	0	1	2
Burseraceae	Dacryodes	rostrata	dicot tree	5	1	3	1	3	1	2	1
Burseraceae	Dacryodes	rugosa	dicot tree	0	0	4	1	0	0	2	1
Caesalpiniaceae	Bauhinia	diptera	dicot liana	1	7	0	0	1	2	0	0
Caesalpiniaceae	Cynometra	elmeri	dicot tree	1	0	0	0	1	0	0	0
Caesalpiniaceae	Dialium	indum	dicot tree	0	0	0	4	0	0	0	3
Caesalpiniaceae	Koompassia	malaccensis	dicot tree	0	0	2	0	0	0	1	0
Caesalpiniaceae	Saraca	declinata	dicot tree	1	0	0	0	1	0	0	0
Caesalpiniaceae	Sindora	leiocarpa	dicot tree	0	0	1	0	0	0	1	0
Caesalpiniaceae	Sindora	*velutina*	dicot tree	1	0	1	0	1	0	1	0

Family	Genus	Species	Plant type	N0	N1	N2	N3	S0	S1	S2	S3
Celastraceae	Lophopetalum	*javanicum*	dicot tree	0	0	1	12	0	0	1	1
Celastraceae	Salacia	*macrophylla*	dicot liana	0	0	1	0	0	0	1	0
Chrysobalanaceae	Atuna	*racemosa*	dicot tree	3	1	1	0	1	1	1	0
Chrysobalanaceae	Parinari	*canaroides*	dicot tree	0	0	1	0	0	0	1	0
Combretaceae	Combretum	*nigricans*	dicot liana	0	11	1	2	0	2	1	1
Connaraceae	Agelaea	*borneensis*	dicot liana	1	1	1	0	1	1	1	0
Connaraceae	Cnestis	*platantha*	dicot liana	2	0	3	0	2	0	3	0
Connaraceae	Connarus	*semidecandrus*	dicot liana	3	1	5	3	2	1	3	1
Convolvulaceae	Erycibe	*sp.*	dicot liana	1	0	0	0	1	0	0	0
Convolvulaceae	Merremia	*mammosa*	dicot liana	0	2	0	0	0	1	0	0
Crypteroniaceae	Crypteronia	*griffithii*	dicot tree	1	3	0	0	1	1	0	0
Cophioglossaceae	Helminthostachys	*zeylanica*	fern tree	0	3	0	0	0	3	0	0
Cyperaceae	Mapania	*latifolia*	monocot grass	1	5	0	0	1	2	0	0
Cyperaceae	*Scleria*	terrestris	monocot grass	2	3	0	0	1	2	0	0
Dilleniaceae	*Dillenia*	suffruticosa	dicot tree	0	1	0	0	0	1	0	0
Dilleniaceae	*Tetracera*	akara	dicot liana	5	0	0	1	2	0	0	1
Dioscoreaceae	*Dioscorea*	pyrofolia	monocot liana	0	1	0	0	0	1	0	0
Dipterocarpaceae	*Cotylelobium*	melanoxylum	dicot tree	0	0	3	3	0	0	2	1
Dipterocarpaceae	*Dipterocarpus*	acutangulus	dicot tree	8	0	1	0	2	0	1	0
Dipterocarpaceae	*Dipterocarpus*	confertus	dicot tree	0	0	0	2	0	0	0	1
Dipterocarpaceae	*Dipterocarpus*	crinitus	dicot tree	1	0	3	4	1	0	2	2
Dipterocarpaceae	*Dipterocarpus*	palembanicus	dicot tree	0	0	0	2	0	0	0	2
Dipterocarpaceae	*Dipterocarpus*	stellatus	dicot tree	0	0	0	2	0	0	0	1
Dipterocarpaceae	*Dryobalanops*	beccarii	dicot tree	0	1	0	0	0	1	0	0
Dipterocarpaceae	*Hopea*	cernua	dicot tree	0	0	16	9	0	0	1	4
Dipterocarpaceae	Hopea	semicuneata	dicot tree	68	0	0	0	6	0	0	0
Dipterocarpaceae	Parashorea	malaanonan	dicot tree	0	1	0	0	0	1	0	0
Dipterocarpaceae	Shorea	agamii	dicot tree	0	0	0	1	0	0	0	1
Dipterocarpaceae	Shorea	atrinervosa	dicot tree	0	0	0	8	0	0	0	3
Dipterocarpaceae	Shorea	beccariana	dicot tree	0	0	7	1	0	0	1	1
Dipterocarpaceae	Shorea	collaris	dicot tree	0	0	1	0	0	0	1	0
Dipterocarpaceae	Shorea	exelliptica	dicot tree	0	0	0	4	0	0	0	1
Dipterocarpaceae	Shorea	guiso	dicot tree	0	3	0	0	0	1	0	0
Dipterocarpaceae	Shorea	laevis	dicot tree	0	0	1	0	0	0	1	0
Dipterocarpaceae	Shorea	leprosula	dicot tree	4	12	0	0	2	1	0	0
Dipterocarpaceae	Shorea	macrophylla	dicot tree	0	0	0	1	0	0	0	1
Dipterocarpaceae	Shorea	macroptera	dicot tree	0	0	0	12	0	0	0	3
Dipterocarpaceae	Shorea	maxwelliana	dicot tree	0	0	0	3	0	0	0	1
Dipterocarpaceae	Shorea	parvifolia	dicot tree	0	17	3	2	0	6	2	2
Dipterocarpaceae	Shorea	patoiensis	dicot tree	7	0	0	3	1	0	0	1
Dipterocarpaceae	Shorea	pauciflora	dicot tree	0	0	1	0	0	0	1	0
Dipterocarpaceae	Shorea	smithiana	dicot tree	0	0	0	3	0	0	0	2
Dipterocarpaceae	Vatica	nitens	dicot tree	1	0	13	3	1	0	3	2
Dipterocarpaceae	Vatica	oblongifolia	dicot tree	3	0	1	1	3	0	1	1

Family	Genus	Species	Plant type	N0	N1	N2	N3	S0	S1	S2	S3
Dipterocarpaceae	Vatica	umbonata	dicot tree	0	0	0	1	0	0	0	1
Dryopteridaceae	Nephrolepis	bisserata	fern herb	0	13	1	25	0	6	1	1
Ebenaceae	Diospyros	borneensis	dicot tree	2	4	0	0	1	3	0	0
Ebenaceae	Diospyros	buxifolia	dicot tree	0	1	2	3	0	1	2	2
Ebenaceae	Diospyros	curranii	dicot tree	1	0	2	0	1	0	1	0
Ebenaceae	Diospyros	densa	dicot tree	0	0	1	0	0	0	1	0
Ebenaceae	Diospyros	macrophylla	dicot tree	14	0	0	0	2	0	0	0
Ebenaceae	Diospyros	sp.1	dicot tree	1	0	0	1	1	0	0	1
Elaeocarpaceae	Elaeocarpus	*stipularis*	dicot tree	0	0	0	1	0	0	0	1
Euphorbiaceae	Antidesma	*montanum*	dicot tree	0	0	0	1	0	0	0	1
Euphorbiaceae	Antidesma	*neurocarpum*	dicot tree	0	1	0	0	0	1	0	0
Euphorbiaceae	Aporosa	*dioica*	dicot tree	0	0	1	1	0	0	1	1
Euphorbiaceae	Aporosa	*nitida*	dicot tree	0	1	0	0	0	1	0	0
Euphorbiaceae	Baccaurea	*sumatrana*	dicot tree	0	1	2	0	0	1	1	0
Euphorbiaceae	Baccaurea	*tetrandra*	dicot tree	0	0	0	1	0	0	0	1
Euphorbiaceae	Chaetocarpus	*castanocarpus*	dicot tree	0	0	1	2	0	0	1	2
Euphorbiaceae	Cleistanthus	*erycibifolius*	dicot tree	4	0	3	1	2	0	2	1
Euphorbiaceae	Cleistanthus	*myrianthus*	dicot tree	1	0	0	0	1	0	0	0
Euphorbiaceae	Croton	*argyratus*	dicot tree	21	0	0	0	8	0	0	0
Euphorbiaceae	Croton	*caudatus*	dicot tree	1	0	0	0	1	0	0	0
Euphorbiaceae	*Drypetes*	kikir	dicot tree	0	0	2	2	0	0	2	1
Euphorbiaceae	*Glochidion*	arborescens	dicot tree	1	2	1	1	1	1	1	1
Euphorbiaceae	*Koilodepas*	brevipes	dicot tree	12	11	17	4	6	4	7	3
Euphorbiaceae	*Macaranga*	gigantea	dicot tree	0	3	1	0	0	2	1	0
Euphorbiaceae	*Macaranga*	hypoleuca	dicot tree	0	17	1	1	0	5	1	1
Euphorbiaceae	*Mallotus*	muticus	dicot tree	3	4	0	0	3	2	0	0
Euphorbiaceae	*Moultonianthus*	leembruggianus	dicot tree	0	0	5	0	0	0	2	0
Euphorbiaceae	*Neoscortechinia*	kingii	dicot tree	0	0	6	1	0	0	3	1
Euphorbiaceae	*Paracroton*	pendulus	dicot tree	1	2	0	0	1	2	0	0
Euphorbiaceae	*Pimelodendron*	griffithianum	dicot tree	3	0	0	2	2	0	0	2
Fagaceae	*Castanopsis*	fulva	dicot tree	0	0	2	0	0	0	1	0
Fagaceae	*Lithocarpus*	coopertus	dicot tree	0	2	0	1	0	2	0	1
Graminae	*Imperata*	cylindrica	monocot grass	0	0	0	2	0	0	0	1
Guttiferae	*Calophyllum*	gracilipes	dicot tree	0	0	11	6	0	0	7	4
Guttiferae	Garcinia	celebica	dicot tree	0	0	1	4	0	0	1	2
Guttiferae	Garcinia	sp.1	dicot tree	0	1	0	0	0	1	0	0
Guttiferae	Kayea	borneensis	dicot tree	1	0	0	0	1	0	0	0
Guttiferae	Mesua	conoidea	dicot tree	0	0	0	1	0	0	0	1
Icacinaceae	Stemonurus	scorpioides	dicot tree	0	0	0	1	0	0	0	1
Lauraceae	Alseodaphne	elmeri	dicot tree	0	2	2		0	2	2	0
Lauraceae	Cryptocarya	crassinervia	dicot tree	0	1	0		0	1	0	1
Lauraceae	Endiandra	kingiana	dicot tree	0	2	0		0	2	0	1

Family	Genus	Species	Plant type	N0	N1	N2	N3	S0	S1	S2	S3
Lauraceae	Eusideroxylon	zwageri	dicot tree	0	3	0	0	0	1	0	0
Lauraceae	Litsea	oppositifolia	dicot tree	0	2	0	0	0	2	0	0
Lauraceae	Phoebe	grandis	dicot tree	0	2	0	4	0	1	0	2
Loganiaceae	Fagraea	racemosa	dicot tree	0	2	1	0	0	2	1	0
Loganiaceae	Strychnos	axillaris	dicot liana	4	5	6	3	2	2	3	2
Lycopodiaceae	Lycopodium	cernuum	fern herb	0	0	0	2	0	0	0	1
Marantaceae	Stachyprhynium	borneensis	monocot herb	0	0	0	1	0	0	0	1
Melastomataceae	Clidemia	hirta	dicot liana	0	7	1	1	0	2	1	1
Melastomataceae	Diplectria	divaricata	dicot liana	0	2	1	0	0	2	1	0
Melastomataceae	Dissochaeta	sp.1	dicot liana	0	6	0	0	0	1	0	0
Melastomataceae	Melastoma	malabathricum	dicot tree	0	1	2	35	0	1	2	2
Melastomataceae	Memecylon	borneensis	dicot tree	1	0	1	0	1	0	1	0
Melastomataceae	Memecylon	edule	dicot tree	2	0	1	0	1	0	1	0
Melastomataceae	Pternandra	azurea	dicot tree	4	0	0	0	2	0	0	0
Melastomataceae	Pternandra	galeata	dicot tree	1	0	0	0	1	0	0	0
Melastomataceae	Pternandra	rostrata	dicot tree	3	8	3	3	2	2	1	1
Meliaceae	Aglaia	sp.1	dicot tree	2	0	0	0	1	0	0	0
Meliaceae	Aglaia	tomentosa	dicot tree	0	1	0	0	0	1	0	0
Menispermaceae	Fibraurea	*tinctorea*	dicot liana	1	0	2	0	1	0	2	0
Mimosaceae	Parkia	*speciosa*	dicot tree	8	0	0	0	2	0	0	0
Moraceae	Artocarpus	*elasticus*	dicot tree	2	0	2	2	2	0	1	1
Moraceae	Artocarpus	*lanceifolius*	dicot tree	1	0	0	0	1	0	0	0
Moraceae	Ficus	*obscura*	dicot tree	0	4	0	1	0	2	0	1
Moraceae	Parartocarpus	*bracteatus*	dicot tree	1	0	0	0	1	0	0	0
Myristicaceae	Horsfieldia	*borneensis*	dicot tree	0	0	1	0	0	0	1	0
Myristicaceae	Horsfieldia	*polyspherula*	dicot tree	1	2	3	0	1	2	3	0
Myristicaceae	Knema	*iners*	dicot tree	0	0	1	0	0	0	1	0
Myristicaceae	Knema	*laurina*	dicot tree	0	1	0	6	0	1	0	4
Myristicaceae	Myristica	*iners*	dicot tree	0	7	0	0	0	1	0	0
Myristicaceae	*Myristica*	villosa	dicot tree	0	0	0	1	0	0	0	1
Myrsinaceae	*Ardisia*	korthalsiana	dicot tree	0	2	0	1	0	2	0	1
Myrsinaceae	*Ardisia*	sp.	dicot tree	1	0	3	0	1	0	2	0
Myrsinaceae	*Ardisia*	sp.1	dicot tree	0	1	0	0	0	1	0	0
Myrsinaceae	*Ardisia*	sp.2	dicot tree	0	0	0	1	0	0	0	1
Myrsinaceae	*Embelia*	javanica	dicot liana	0	2	2	0	0	1	1	0
Myrsinaceae	*Maesa*	macrothyrsa	dicot liana	0	0	1	0	0	0	1	0
Myrtaceae	*Syzygium*	caudatilimba	dicot tree	3	0	0	0	1	0	0	0
Myrtaceae	*Syzygium*	sp.4	dicot tree	0	0	2	2	0	0	1	1
Myrtaceae	*Syzygium*	tawahense	dicot tree	3	0	20	7	2	0	8	4
Ochnaceae	*Gomphia*	serrata	dicot tree	1	0	1	1	1	0	1	1
Oleaceae	*Chionanthus*	sp.1	dicot tree	9	1	0	15	5	1	0	4
Oleaceae	*Chionanthus*	sp.2	dicot tree	2	0	0	0	1	0	0	0

Family	Genus	Species	Plant type	N0	N1	N2	N3	S0	S1	S2	S3
Palmae	*Calamus*	sp.	palm rotan	1	0	0	0	1	0	0	0
Palmae	*Daemonorops*	sabut	palm rotan	8	3	1	1	5	3	1	1
Palmae	*Korthalsia*	furtadoana	palm rotan	3	1	1	1	2	1	1	1
Palmae	Oncosperma	horidum	palm tree	2	1	0	0	1	1	0	0
Papilionaceae	Fordia	splendidissima	dicot tree	5	4	22	17	3	2	9	8
Piperaceae	Piper	sp.	dicot liana	0	0	0	2	0	0	0	1
Polygalaceae	Xanthophyllum	affine	dicot tree	5	0	0	0	3	0	0	0
Polygalaceae	Xanthophyllum	ellipticum	dicot tree	1	2	0	0	1	1	0	0
Polygalaceae	Xanthophyllum	obscurum	dicot tree	2	0	1	0	1	0	1	0
Polygalaceae	Xanthophyllum	sp.1	dicot tree	0	1	0	0	0	1	0	0
Polypodiaceae	Drynaria	sparsisora	fern epiphyt	0	0	0	1	0	0	0	1
Rhamnaceae	Ventilago	sp.	dicot liana	0	0	1	0	0	0	1	0
Rhamnaceae	Ziziphus	borneense	dicot liana	0	0	1	0	0	0	1	0
Rubiaceae	Anthocephalus	chinensis	dicot tree	0	1	0	0	0	1	0	0
Rubiaceae	Diplospora	malaccensis	dicot tree	2	0	0	0	1	0	0	0
Rubiaceae	Gardenia	tubifera	dicot tree	2	0	0	0	1	0	0	0
Rubiaceae	Hypobathrum	sp.1	dicot tree	0	2	0	0	0	2	0	0
Rubiaceae	Ixora	fucosa	dicot shrub	1	3	2	4	1	1	1	4
Rubiaceae	Ixora	lobii	dicot shrub	0	1	0	0	0	1	0	0
Rubiaceae	Nauclea	subdita	dicot tree	0	1	0	0	0	1	0	0
Rubiaceae	Pleiocarpidia	polyneura	dicot tree	2	5	0	0	2	3	0	0
Rubiaceae	Psychotria	sp.1	dicot shrub	0	3	0	0	0	2	0	0
Rubiaceae	Tarenna	rostrata	dicot tree	0	3	0	0	0	1	0	0
Rubiaceae	Timonius	flavescens	dicot tree	0	0	0	1	0	0	0	1
Rubiaceae	Uncaria	cordata	dicot liana	0	3	0	0	0	2	0	0
Rubiaceae	Urophyllum	arborescens	dicot tree	0	0	0	3	0	0	0	2
Sabiaceae	Meliosma	sumatrana	dicot tree	0	2	0	0	0	1	0	0
Sapindaceae	Dimocarpus	longan	dicot tree	1	2	0	0	1	2	0	0
Sapindaceae	Guioa	sp.	dicot tree	1	0	0	0	1	0	0	0
Sapotaceae	Madhuca	kingiana	dicot tree	1	0	0	0	1	0	0	0
Sapotaceae	Madhuca	*malaccensis*	dicot tree	2	4	24	15	2	1	6	5
Sapotaceae	Madhuca	*sericea*	dicot tree	0	0	1	0	0	0	1	0
Sapotaceae	Palaquium	*calophyllum*	dicot tree	0	5	4	0	0	2	3	0
Sapotaceae	Palaquium	*stenophyllum*	dicot tree	3	0	0	0	2	0	0	0
Sapotaceae	Payena	*acuminata*	dicot tree	0	7	0	0	0	1	0	0
Schizaeaceae	Lygodium	*circinatum*	fern vine	1	9	13	13	1	2	2	2
Schizaeaceae	Lygodium	*microphyllum*	fern vine	0	0	0	2	0	0	0	1
Selaginellaceae	*Selaginella*	caulescens	fern herb	0	12	0	0	0	5	0	0
Simaroubaceae	*Allanthospermum*	borneensis	dicot tree	0	0	0	2	0	0	0	1
Simaroubaceae	*Irvingia*	malayana	dicot tree	0	1	0	0	0	1	0	0
Sterculiaceae	*Heritiera*	elata	dicot tree	2	0	0	0	2	0	0	0
Sterculiaceae	*Scaphium*	macropodum	dicot tree	0	0	1	7	0	0	1	2
Symplocaceae	*Symplocos*	crassipes	dicot tree	7	3	0	0	5	2	0	0

Family	Genus	Species	Plant type	N0	N1	N2	N3	S0	S1	S2	S3
Thymelaeaceae	*Aquilaria*	malaccensis	dicot tree	0	1	0	0	0	1	0	0
Thymelaeaceae	*Gonystylus*	*macrophyllus*	dicot tree	1	0	2	3	1	0	2	3
Tiliaceae	Grewia	*fibrocarpa*	dicot tree	0	1	0	1	0	1	0	1
Tiliaceae	Microcos	*crassifolia*	dicot tree	2	1	0	0	1	1	0	0
Tiliaceae	Pentace	*adenophora*	dicot tree	0	4	0	0	0	2	0	0
Tiliaceae	Pentace	*polyantha*	dicot tree	0	0	0	9	0	0	0	1
Ulmaceae	Gironniera	*nervosa*	dicot tree	1	1	3	1	1	1	2	1
Verbenaceae	Teijsmanniodendron	*pteropodium*	dicot tree	4	0	0	1	3	0	0	1
Verbenaceae	Vitex	*vestita*	dicot tree	0	1	1	0	0	1	1	0
Vitaceae	Cissus	*angustata*	dicot liana	0	1	0	0	0	1	0	0
Zingiberaceae	Alpinia	*galanga*	monocot herb	0	3	9	0	0	2	2	0
Zingiberaceae	Etlingera	*borneensis*	monocot herb	0	2	0	1	0	1	0	1
Zingiberaceae	Globba	*brachyanthera*	monocot herb	0	0	1	0	0	0	1	0

Appendix 4

List of abundance all birds species observed in total 5 point counts with 8 point count visits in all sites. After each scientific name, vernacular name, foraging layer (T = terrestrial; U = understorey; A = arboreal) and diet (N = nectarivore ; F = frugivore ; FI = frugivore / insectivore ; FC = frugivore / carnivore ; I = insectivore ; IC = insectivore / carnivore) and diet per forest disturbance type (0 = primary forest1 in Berau, 1 = secondary forest, 1 year after logged, 2 = 5 years after logged, 3 = 10 years after logged, 4 = primary forest2 in Sungai Wain, 5 = disturbed forest in Pusrehut).

Names		Foraging layer	Diet	N0	N4	N1	N2	N3	N5
Scientific name	**Common name**								
Abroscopus supercillaris	Yellow-bellied warbler	U	I	0	0	4	0	2	0
Aceros corrugatus	Wrinkled hornbill	A	FC	1	0	0	3	0	2
Actenoides concretus	Chestnut-collared kingfisher	T	I	1	0	1	0	0	0
Aegithina viridissima	Green Iora	A	I	0	0	1	0	0	0
Alcedo meninting	Blue-eared kingfisher	U	IC	0	0	0	1	1	1
Alcippe brunneicauda	Brown fulvetta	A	FI	2	0	8	3	14	0
Anorrhinus galeritus	Bushy-crested hornbill	A	FC	0	3	2	0	0	0
Anthracocceros Malay Pnus	Asian black hornbill	A	FC	4	8	5	3	1	5
Anthreptes simplex	Plain Sunbird	U	I	0	0	0	2	0	0
Aplonis panayensis	Asian glossy starling	U	FI	0	7	0	0	0	3
Arachnothera chrysogenys	Yellow-eared spiderhunter	A	N	0	0	0	1	0	0
Arachnothera flavigaster	Spectacled spiderhunter	A	FI	4	1	0	1	1	0
Arachnothera longirostra	Little Spiderhunter	U	N	29	11	23	15	10	12
Arachnothera modesta	Grey-breasted spiderhunter	U	N	1	0	0	1	0	0
Arachnothera robusta	Long-billed spiderhunter	A	N	1	0	0	0	0	2
Argusianus argus	Great Argus	T	FI	0	1	0	0	1	0
Blythipicus rubiginosus	Maroon woodpecker	U	I	0	0	0	0	4	1
Buceros rhinoceros	Rhinoceros hornbill	A	FC	3	1	7	4	4	6
Buceros vigil	Helmeted Hornbill	A	FC	6	0	0	0	0	2
Cacomantis merulinus	Plaintive cuckoo	A	I	0	0	2	4	1	0
Cacomantis sonneratii	Banded bay cuckoo	A	I	7	1	3	0	2	2
Calorhampus fuliginosus	Brown Barbet	A	I	0	18	0	0	0	3
Calyptomena viridis	Green broadbill	A	F	5	0	8	9	3	0
Caprimulgus macrurus	Large-tailed nightjar	T	I	0	0	0	0	0	5
Carpococcyx radiatus	Bornean Ground-Cuckoo	A	FI	0	1	0	0	0	0
Celeus brachyurus	Rufous woodpecker	U	I	2	0	5	2	0	0
Centropus bengalensis	Lesser Coucal	U	I	0	0	0	0	0	2
Centropus rectunguis	Short-toed coucal	U	IC	1	0	0	0	0	0
Centropus sinensis	Greater Coucal	T	IC	3	0	2	0	1	1

Names		Foraging layer	Diet	N0	N4	N1	N2	N3	N5
Scientific name	**Common name**								
Ceyx erithaca	Black-Backed Kingfisher	U	I	0	1	0	0	0	1
Ceyx erithacus	Oriental dwarf kingfisher	T	I	0	4	0	0	0	6
Ceyx rufidorsa rufidorsa	Rufous-backed kingfisher	U	I	1	0	1	2	2	0
Chalcoparia singalensis	Ruby-cheeked sunbird	A	FI	0	0	0	1	0	0
Chloropsis cyanopogon	Lesser green leafbird	A	F	2	0	0	0	0	0
Chloropsis sonnerati	Greater green leafbird	U	F	0	8	7	0	2	6
Chrysococcyx minutillus	Little bronze cuckoo	A	I	0	0	1	0	0	0
Chrysococcyx xanthorhynchus	Violet cuckoo	U	I	1	0	3	0	0	0
Copsychus malabaricus	White-rumped shama	U	I	1	0	1	0	6	2
Coracina fimbriata	Lesser cuckoo-shrike	A	FI	3	0	10	0	8	0
Corvus enca	Slender-billed crow	A	IC	0	0	0	0	3	1
Criniger bres	Grey-cheeked bulbul	U	FI	3	7	5	0	2	3
Criniger finschii	Finsch's Bulbul	U	F	0	1	0	0	0	1
Criniger phaeocephalus	Yellow-bellied bulbul	U	FI	5	10	8	1	3	3
Cuculus micropterus	Indian cuckoo	A	I	9	0	10	6	3	0
Culicicapa ceylonensis	Grey-headed canary flycatcher	U	I	0	1	0	1	0	0
Curniculus lugubris	Square-tailed drongo-cuckoo	A	I	1	0	1	0	5	0
Cyornis superbus	Bornean Blue Flycatcher	A	I	0	1	0	0	0	0
Cyornis turcosus	Malaysian blue flycatcher	U	I	1	0	0	0	0	0
Cyornis unicolor	Pale blue flycatcher	A	I	0	0	1	0	0	0
Dendrocopus canicapillus	Grey-Capped Woodpecker	A	FI	0	0	0	0	0	0
Dicaeum concolor	Plain Flowerpecker	A	N	0	2	0	0	0	1
Dicaeum everetti	Brown-Backed Flowerpecker	A	N	0	0	0	0	0	1
Dicaeum trigonostigma	Orange-bellied flowerpecker	U	F	4	8	11	2	0	20
Dicrurus aeneus	Bronzed drongo	A	I	17	0	2	7	7	0
Dicrurus paradiseus	Greater racquet-tailed drongo	A	I	7	9	5	11	18	9
Dinopium rafflesii	Olive-backed woodpecker	U	I	0	0	1	0	1	0
Dryocopus javensis	White-bellied woodpecker	A	FI	0	0	2	1	0	3
Enicurus leschenaulti	White-crowned forktail	A	I	1	7	2	0	2	0
Eurostopodus macrotis	Great eared nightjar	T	I	0	0	0	0	0	1
Eurostopodus temmickii	Malaysian Eared Nightjar	T	I	0	0	0	0	0	1
Eurostopodus temminckii	Malaysian Eared Nightjar	A	I	0	0	0	0	0	2
Eurylaimus javanicus	Banded broadbill	A	I	0	3	2	0	3	2
Eurylaimus ochromalus	Black-and-Yellow Broadbill	A	I	23	18	22	17	27	15
Gracula religiosa	Hill Myna	A	FI	4	41	20	14	5	4
Harpactes diardii	Diard's trogon	A	FI	1	3	1	0	2	0
Harpactes duvaucelii	Scarlet-rumped trogon	U	I	6	2	0	1	3	1
Harpactes kasumba	Red-naped trogon	A	I	1	0	2	1	0	0
Harpactes orrophaeus	Cinnamon-rumped trogon	A	FI	0	2	0	1	0	0
Hierococcyx vagans	Moustached Hawk-cuckoo	U	I	1	0	0	0	0	0
Hirundo tahitica	Pacific Swallow	A	I	0	2	0	0	0	0

Names		Foraging layer	Diet	N0	N4	N1	N2	N3	N5
Scientific name	**Common name**								
Hypogramma hypogrammicum	Purple-naped sunbird	U	N	8	4	5	9	5	4
Hypothymis azurea	Black-naped monarch	A	I	5	3	10	8	7	2
Iole olivacea	Buff-vented bulbul	U	FI	8	0	3	5	2	4
Irena puella	Asian fairy-bluebird	A	F	18	2	9	1	8	0
Ixos malaccensis	Streaked bulbul	A	FI	3	0	0	6	5	0
Lacedo pulchella	Banded kingfisher	U	I	0	0	0	1	2	0
Lonchura fuscans	Dusky munia	U	F	0	0	0	2	1	2
Loriculus galgulus	Blue-crowned hanging parrot	A	N	4	3	7	6	5	9
Macronous bornensis bornensis	Bold-striped tit-babbler	U	I	2	2	2	2	5	0
Macronous ptilosus	Fluffy-backed tit-babbler	U	I	0	8	1	3	8	21
Malacopteron affine	Sooty-capped babbler	U	I	0	4	0	0	4	0
Malacopteron magnum	Rufous-crowned babbler	A	I	11	2	6	18	21	0
Malcopteron cinereum	Scaly-crowned babbler	U	I	3	0	8	4	1	0
Megalaima australis	Blue-eared barbet	A	FI	8	5	15	11	12	17
Megalaima chrysopogon	Golden-whiskered barbet	A	FI	8	0	0	3	16	0
Megalaima eximia	Bornean barbet	U	F	0	24	0	0	0	18
Megalaima henricii	Yellow-crowned barbet	A	F	7	0	3	9	11	8
Megalaima mystacophanos	Red-throated barbet	A	FI	24	0	1	0	2	0
Megalaima rafflesii	Red-crowned barbet	A	FI	4	33	13	6	0	5
Meiglyptes tristis	Buff-rumped woodpecker	A	I	1	3	1	1	0	0
Meiglyptes tukki	Buff-necked woodpecker	U	I	1	0	0	0	0	4
Merops viridis	Blue-Throated Bee-eater	A	I	0	13	0	0	0	10
Mulleripicus pulverulentus	Great slaty woodpecker	A	I	0	0	3	1	0	0
Nectarinia jugularis	Eastern crimson sunbird	U	N	0	0	0	1	1	0
Nectarinia sperata	Purple-throated Sunbird	U	N	0	0	0	0	0	2
Ninox sculata	Boobook	A	FC	0	1	0	0	0	0
Nyctyornis amictus	Red-bearded bee-eater	A	I	1	0	0	0	0	0
Oriolus xanthonotus	Dark-throated oriole	A	FI	0	0	1	0	0	0
Orthotomus atrogularis	Dark-necked tailorbird	U	I	0	4	4	3	3	9
Orthotomus ruficeps	Red-headed tailorbird	U	I	2	10	4	6	4	15
Orthotomus sericeus	Rufous-tailed tailorbird	U	I	0	0	4	2	3	4
Pamathorhinus montanus	Chestnut-backed scimitar babbler	T	F	0	3	0	0	0	0
Pellorenum capistratum	Black-capped babbler	T	I	1	6	2	1	1	3
Pericrocotus flammeus	Scarlet minivet	A	I	0	0	2	0	0	3
Pericrocotus igneus	Itierym Inivet	T	I	0	0	0	0	0	1
Phaenicophaenus curvirostris	Chestnut-breasted malkoha	U	IC	0	0	2	0	0	3
Phaenicophaeus chlorophaeus	Raffles's malkoha	A	I	0	0	2	0	2	0
Phaenicophaeus curvirostris	Chestnut -Breastedmalkoh	A	I	0	1	0	0	0	0
Philentoma pyrrhopterum	Rufous-winged philentoma	U	I	0	0	3	0	0	0

Names		Foraging layer	Diet	N0	N4	N1	N2	N3	N5
Scientific name	**Common name**								
Picumnus innominatus	Speckled piculet	A	I	0	1	0	0	0	0
Picus miniaceus	Banded woodpecker	A	I	1	4	0	0	0	0
Picus puniceus	Crimson-winged woodpecker	A	I	0	0	0	1	0	1
Pitta arquata	Blue-Banded Pitta	T	I	0	2	0	0	0	2
Pitta baudii	Blue-headed pitta	T	I	8	0	0	0	1	1
Pitta granatina	Garnet Pitta	T	I	17	2	5	11	6	3
Pitta sordida muelleri	Hooded pitta	U	I	1	0	0	0	0	0
Platylophus galeritus	Crested jay	U	I	4	4	1	1	1	0
Platysmurus atterimus	Bornean black magpie	A	I	2	16	2	6	9	0
Polyplectron schleiermacheri	Bornean Peacock-Pheasant	T	F	0	2	0	0	0	2
Pomatorhinus mantanus	Chestnut-backed scimitar babbler	A	I	1	4	1	0	0	1
Prinochilus thoracicus	Scarlet-breasted flowerpecker	A	FI	1	0	0	0	0	0
Prinochilus xanthopygius	Yellow-rumped flowerpecker	A	N	2	1	4	2	0	0
Prionochilus maculatus	Yellow-breasted flowerpecker	U	N	3	2	1	4	3	3
Prionochilus percussus	Crimson-Breasted flowerpecker	A	F	0	0	0	0	0	2
Psittacula longicauda	Long-tailed parakeet	A	F	0	0	1	0	0	0
Ptilocichla leucogrammica	Bornean wren-babbler	T	I	1	0	0	1	1	0
Pycnonotus atriceps atriceps	Black-headed bulbul	A	FI	14	30	6	8	3	13
Pycnonotus brunneus	Red-eyed bulbul	U	FI	41	34	33	25	41	28
Pycnonotus cyaniventris	Grey-bellied bulbul	U	FI	2	0	1	0	0	0
Pycnonotus erythrophthalmos	Spectacled bulbul	A	FI	0	0	0	0	2	0
Pycnonotus eutilotus	Puff-backed bulbul	U	FI	0	0	0	0	2	1
Pycnonotus goavier	Yellow-vented bulbul	U	FI	1	2	2	1	0	14
Pycnonotus plumosus	Olive-winged bulbul	U	FI	2	0	0	0	0	0
Pycnonotus simplex	Cream-vented bulbul	A	FI	13	4	7	17	9	5
Pycnonotus zeylanicus	Straw-headed bulbul	U	FI	1	0	0	0	0	0
		U	I	0	1	1	2	8	0
Rhinomyias umbratilis	Grey-chested jungle flycatcher								
Rhipidura javanica	Pied fantail	U	I	0	0	1	1	0	0
Rhipidura perlata	Spotted Fantail	A	I	0	0	0	0	2	0
Rhyticeros undulatus	Wreathed hornbill	A	FC	0	1	0	0	1	1
Sitta frontalis	Velvet-fronted nuthatch	U	I	0	0	1	0	0	0
Stachyris erythroptera	Chestnut-winged babbler	U	I	20	5	15	13	23	3
Stachyris maculata	Chestnut-rumped babbler	U	I	16	18	13	13	20	9
Stachyris nigricollis	Black-throated babbler	A	I	6	8	0	2	5	0
Tephrodoris gularis	Large Wood Shrike	A	I	2	0	1	1	0	0
Terpsiphone paradisi	Asian-paradise flycatcher	U	I	11	4	8	2	2	0
Treron cappelei	Large green pigeon	A	F	0	1	0	0	1	0
Treron curvirostris	Thick-billed green pigeon	A	F	6	0	5	1	3	0
Treron olax	Little green pigeon	A	F	9	1	7	1	0	0
Trichastoma bicolor	Ferruginous babbler	U	I	1	3	0	2	5	0
Trichastoma malaccense	Short-tailed babbler	T	I	7	30	9	16	8	14

Names		Foraging layer	Diet	N0	N4	N1	N2	N3	N5
Scientific name	**Common name**								
Trichastoma rostratum	White-chested babbler	T	I	0	1	0	0	1	3
Trichastoma sepiarium	Horsfield's babbler	T	I	4	1	1	0	0	0
Trichixos pyrropygus	Rufous-tailed shama	A	I	17	5	14	3	5	1
Tricholestes criniger	Hairy-backed bulbul	U	FI	24	0	10	5	4	1

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Curriculum vitae

Arbainsyah was born in Samboja, East Kalimantan, Indonesia, on 7th May 1975 and spent his formative years in Samboja, where he attended SMA Harapan senior high school. After he finished in 1993 he worked in PT Tunggal Yudi Plywood Sawmill and in 1994 he worked in the International MOF-Tropenbos Kalimantan Project at the Forest Research Station on Biodiversity group (Botany) at Wanariset Samboja (WAN) Herbarium, were he was responsible for data entry (BRAHMS), routine herbarium management, plant identification, and Ecological plot establishment. In 1996 he entered the Tridharma University at the Faculty of Biology, in Balikpapan, East Kalimantan.

In 2005 he continued his study for a Master of Science at Leiden University in the Faculty of Biology, under the program Biodiversity and Natural Products, with a fellowship from the GIBBON Foundation. His MSc project was supervised by Dr. F. Adema and Dr. P.J.A. Kessler. His minor subject was about 'A Revision of Asia-Facific Fabaceae (Leguminosae-Papilionaceae) the genus Ormocarpum', and his major subject covered 'A pictorial field guide to fruits and seeds as major animal food resources of East Kalimantan, Indonesia'. In 2012 he received a fellowship grant from the LOUWES fund for his PhD at the Institute of Environmental Sciences (CML: Centrum voor Mileuwetenschappen Leiden), at the Department of Conservation Biology, University of Leiden, The Netherlands. He undertook a research project on 'The impact of Sustainable Forest Management on plant and bird diversity in East Kalimantan, Indonesia' under the supervision of Prof. G.R. de Snoo, Prof. H.H. de Iongh, Dr. C.J.M. Musters (University of Leiden) and Prof. W. Kustiawan (Universitas Mulawarman).

During 1997 to 2012 he acted as a consultant for several projects as an assistant trainer for plant identification in the Forest Research Institute Samarinda, Berau Forest Management Project, PT. Maruwai Coal and CIFOR. In order to improve his skills he visited Leiden University (Nederland) several times during 1979-2002 to be trained for Database Management of the Herbarium and Tropical plant identification, Ethnobotanical Knowledge Systems. He also followed an International course on Economic Botany, a Course on Web Taxonomy and Biodiversity Information Processing ETI BioInformatica, a Course using R in

Data Analysis, and Taxonomy of Sulawesian plant families in Sam Ratulangi University, Manado, North Sulawesi, Indonesia. In 2003 he worked at the Borneo Orangutan Survival (BOS) Foundation as a Tropical Botanist and Ecologist. In 2007 he attended the Flora Malesiana VII Symposium in Leiden University as a presenter. In 2008 he worked with the Eco Integrated Indonesia (EII) Foundation as a Tropical Botanist and Ecologist. In 2010 he attended the Flora Malesiana VIII Symposium in Singapore Botanic Garden,in Singapore, as a presenter. He is currently 'Chairman of the Yayasan Merdeka Pratama'.

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